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Distortionless - Trouble-Free - Endur
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HADFIELDS LTD., EAST HECLA WORKS, SHEFFIELD, ENGLAND

Painting by Eric Fraser F.S.I.A.

TRADE WINDS No 4

THE CAPE OF GOOD HOPE

Before the fifteenth century, Mediterranean seamen scarcely ventured out of sight of land. Ships were still navigated by landmarks although the compass had probably been introduced into Europe during the twelfth century. Trade with the East remained important as expansion was curbed by the frozen North, the Sahara Desert and the winds of the North Atlantic.

The age-old routes from the East to the Mediterranean began to be harassed and plundered by the incursions of the Turks into Asia Minor, so that the urge to conquer the Atlantic winds and seek an ocean passage to the East acquired a new stimulus.

The Portuguese were destined to take the lead as they had perforce to learn their seamanship in the stern Atlantic fringes. They were fearless seamen of no mean ability and under Prince Henry the Navigator, a college was founded which devised improved sailing methods and navigation. The method of sailing against adverse winds was discovered and so solved the problem of beating back against the Trade Winds of the Atlantic.

Year by year new trading posts were established on the African coast until in 1487, Bartholomew Diaz reached Algoa Bay unaware that he had rounded the southern point of Africa. On his return he sighted it and named it "Cape of Good Hope." In 1498 Vasco da Gama rounded the Cape again, and thence steered across the Indian Ocean to Calcutta.

The sea route to the East was open. Pepper, nutmeg, cloves and ginger; fragrant spices, musk and medicines; sapphires, rubies, pearls and diamonds, all came pouring into Lisbon. In their little ships of no more than 400 tons burden, the Portuguese sent in return, lead, silver, copper, mercury, alum and other goods.

Dutch, French, and lastly, the British followed the lead of the Portuguese. Britain rapidly assumed a position of importance and soon eclipsed all other rivals for the Eastern trade.

Ships became larger and less encumbered with fighting men. By taking the Trade Winds far into the Atlantic before making the easting, the tedious coastal crawl round Africa became unnecessary. Trade was opened up not only in Arabia, the Persian Gulf and India, but in Malaya, China and Formosa.

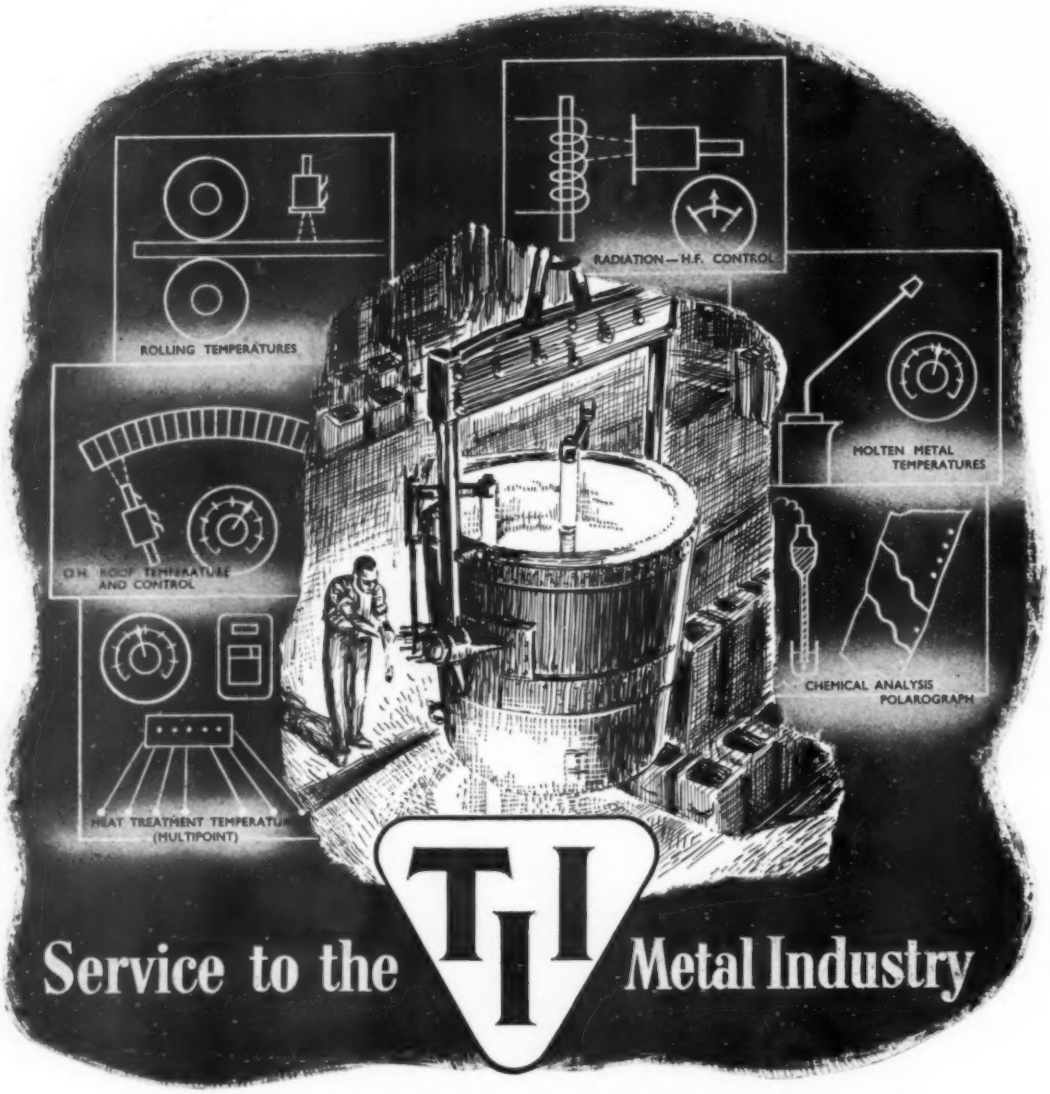
In this great expansion Britain became pre-eminent. As Venice declined so London rose. English enterprise assumed a new character which culminated in the world-wide seaborne trade of the nineteenth century.

THE UNITED STEEL COMPANIES LTD

THE UNITED STEEL COMPANIES LIMITED, SHEFFIELD

STEEL PEECH & TOZER, SHEFFIELD · SAMUEL FOX & CO. LTD., SHEFFIELD · APPLEBY-FRODINGHAM STEEL COMPANY, SCUNTHORPE, LINCS.
WORKINGTON IRON & STEEL COMPANY, WORKINGTON · UNITED STRIP & BAR MILLS, SHEFFIELD · UNITED COKE & CHEMICALS CO. LTD., TREETON

USP 60



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Rapid and accurate estimations for the analysis of ferrous and non-ferrous metals and alloys, e.g. lead and copper in steel, zinc in aluminium. Also trace metals in food and drink . . . rates of corrosion . . . analysis of water for industrial purposes, e.g. sulphating of boilers . . . countless other applications.

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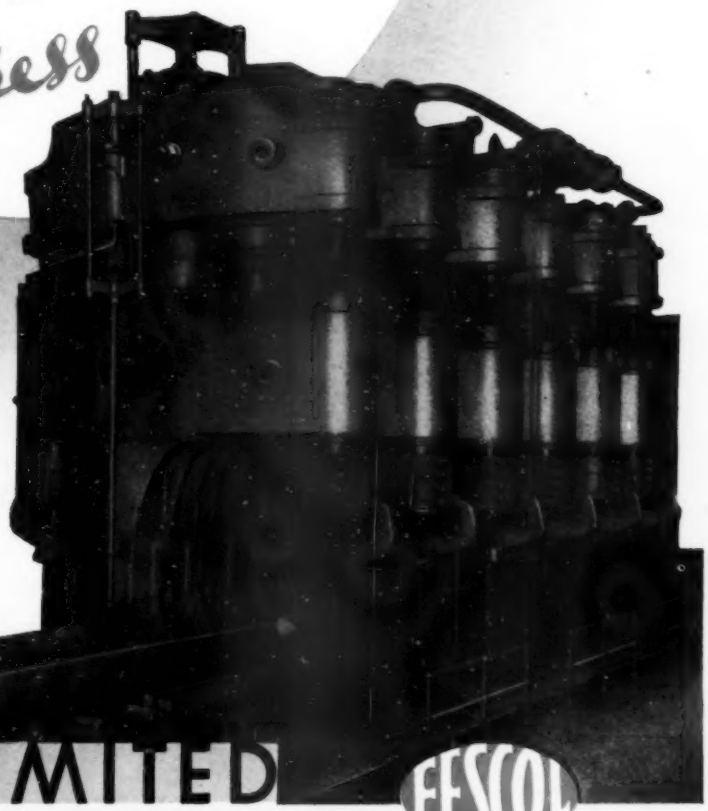
70 RAMS 'FESCOL'-ised

to maintain efficiently this 8,000 ton Press



A hydraulic ram is as good as — no better than — its packing. The life of this vital working part is preserved and prolonged by the "**FESCOL**" process of metal deposition, which eliminates corrosion and arrests the progressive effects of wear.

Over 70 rams on this 8,000-ton Bending Press have been "**FESCOL**"-ised in order to maintain maximum efficiency. The press is the property of Messrs. Babcock & Wilcox, Ltd., to whom we are indebted for permission to reproduce the photograph.

List No. M.U.2 fully describes the "**FESCOL**" process and its application to the treatment of rams and many other parts.

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Much can be done in the design stage to facilitate the production of intricate castings and we invite you to use our experience.

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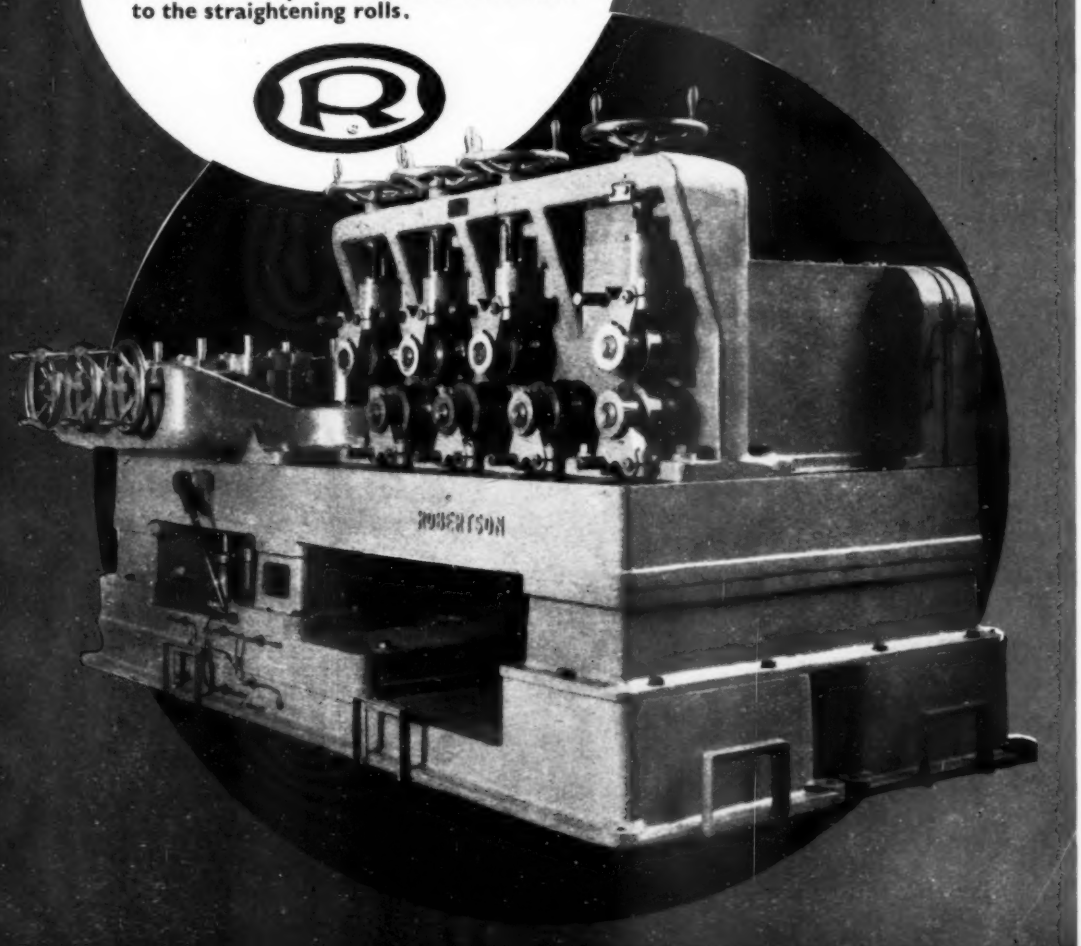
12 Roll Two Way Straightening Machine for high tensile steel bars in hexagons and other straight sided sections. The machine is fitted with a pair of feed rolls in addition to the straightening rolls.



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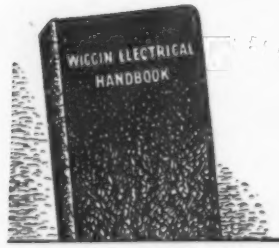

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our
ELECTRICAL RESISTANCE
HANDBOOK
May we send you a copy?

Wire

DRAWN BY MERVYN WILSON

But, with apologies to our artist, we think we draw better *wire, of which our Brightray is an outstanding example.*

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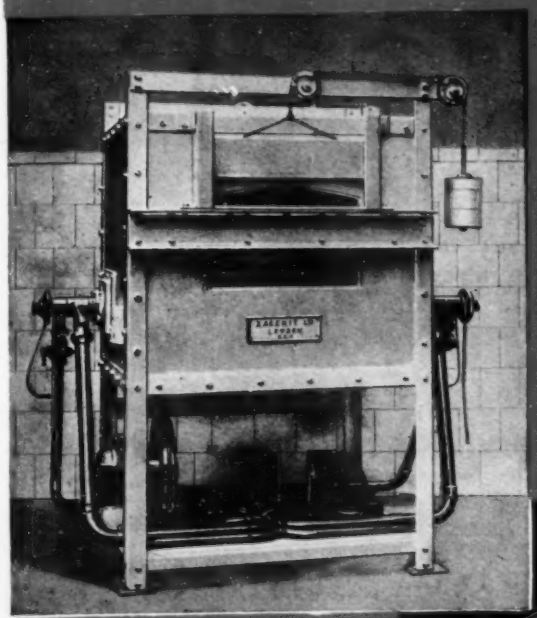
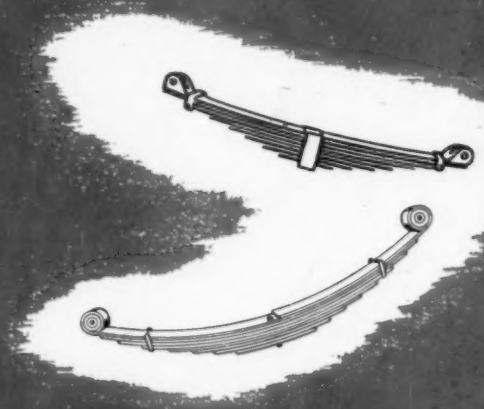
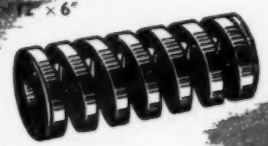
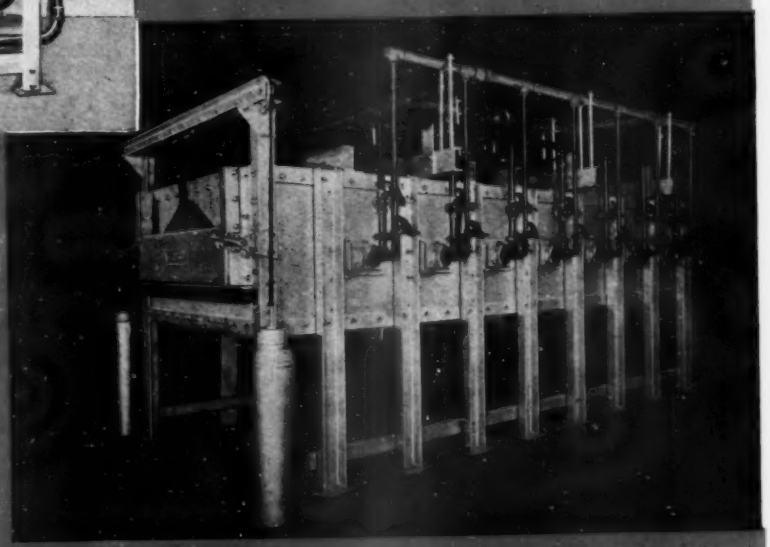
GAS FURNACES for SPRING MANUFACTURE





RECENT INSTALLATIONS:
51" × 24" × 9" 48" × 24" × 8" 27" × 32" × 5"
24" × 24" × 6" 24" × 15" × 9" 27" × 9" × 4"
27" × 27" × 12"
27" × 12" × 6"





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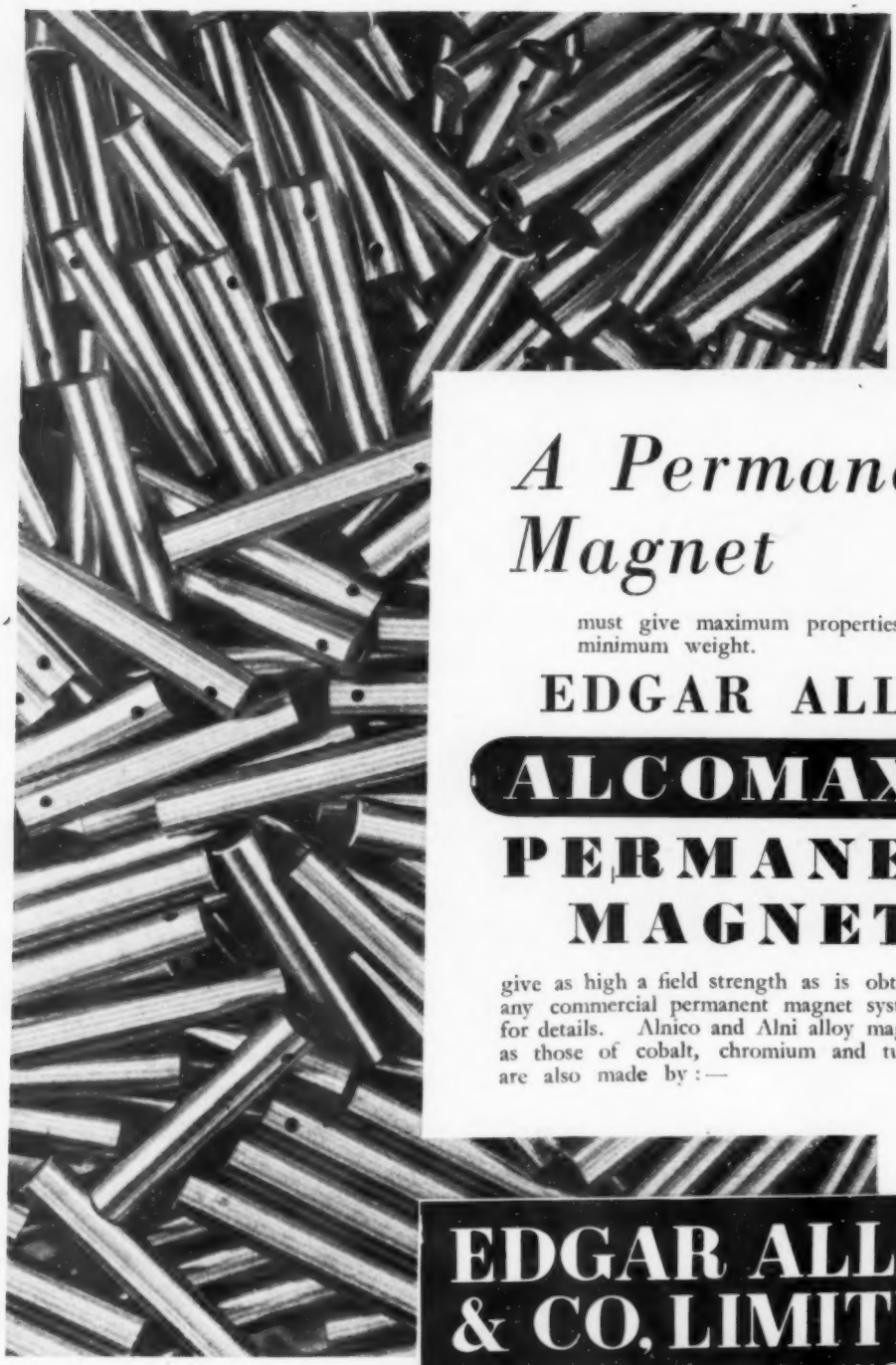

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must give maximum properties with minimum weight.

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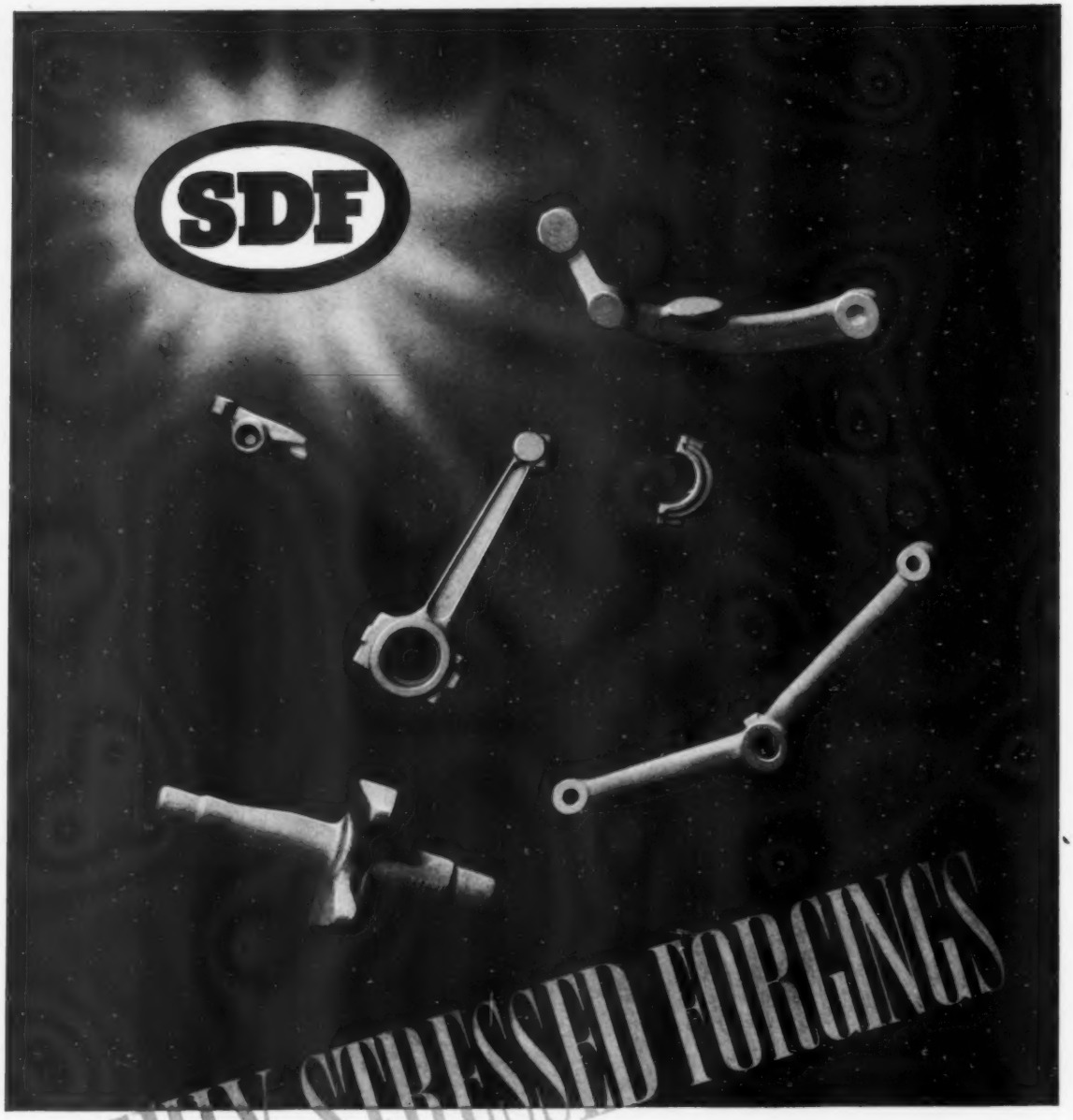

PARAMOUNT CONSIDERATIONS: Sound production, with controlled grain-flow; brought through to dimensional precision and correctly heat treated.

SMETHWICK DROP FORGINGS LTD

SMETHWICK AND KIDDERMINSTER ENGLAND

STRESS-RELIEVING FURNACE

"Priest" Furnace for the stress relief of fabricated steel parts and iron castings, at the Rugby works of The British Thomson-Houston Co., Ltd.; internal dimensions 26 ft. 6 in. long x 17 ft. 6 in. wide x 11 ft. 0 in. high. Fired by coke producer gas from Priest producer, heat application through ported bogie hearth. Lined completely with "Hot Face" insulation; flat suspended roof; full temperature and pressure control equipment.

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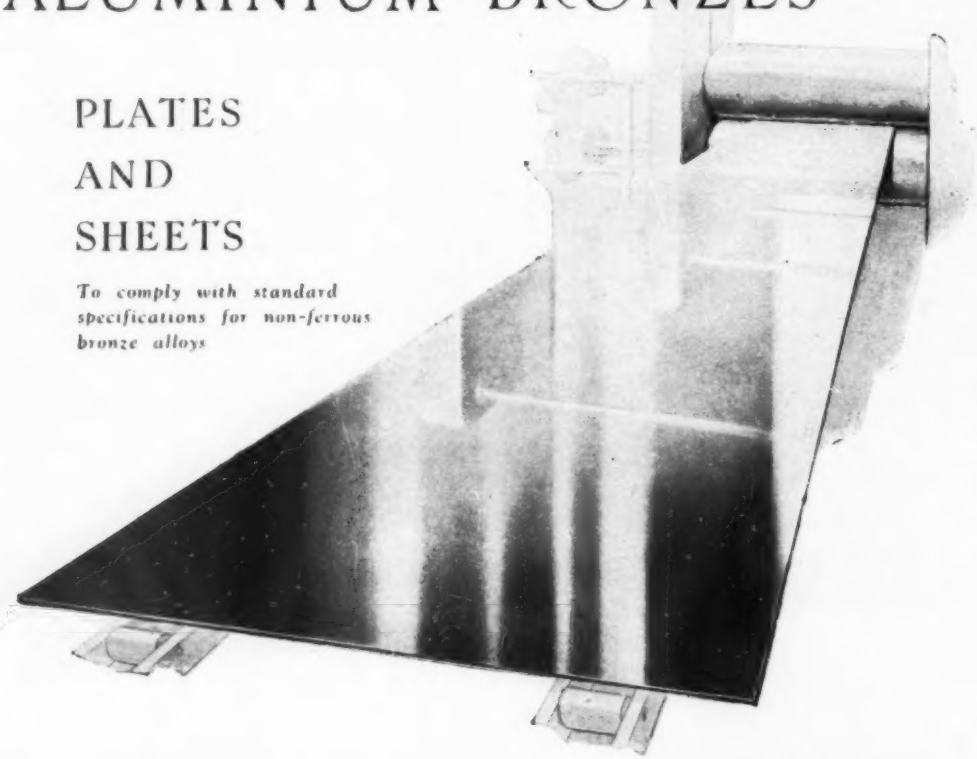
PLATES
AND
SHEETS

To comply with standard specifications for non-ferrous bronze alloys



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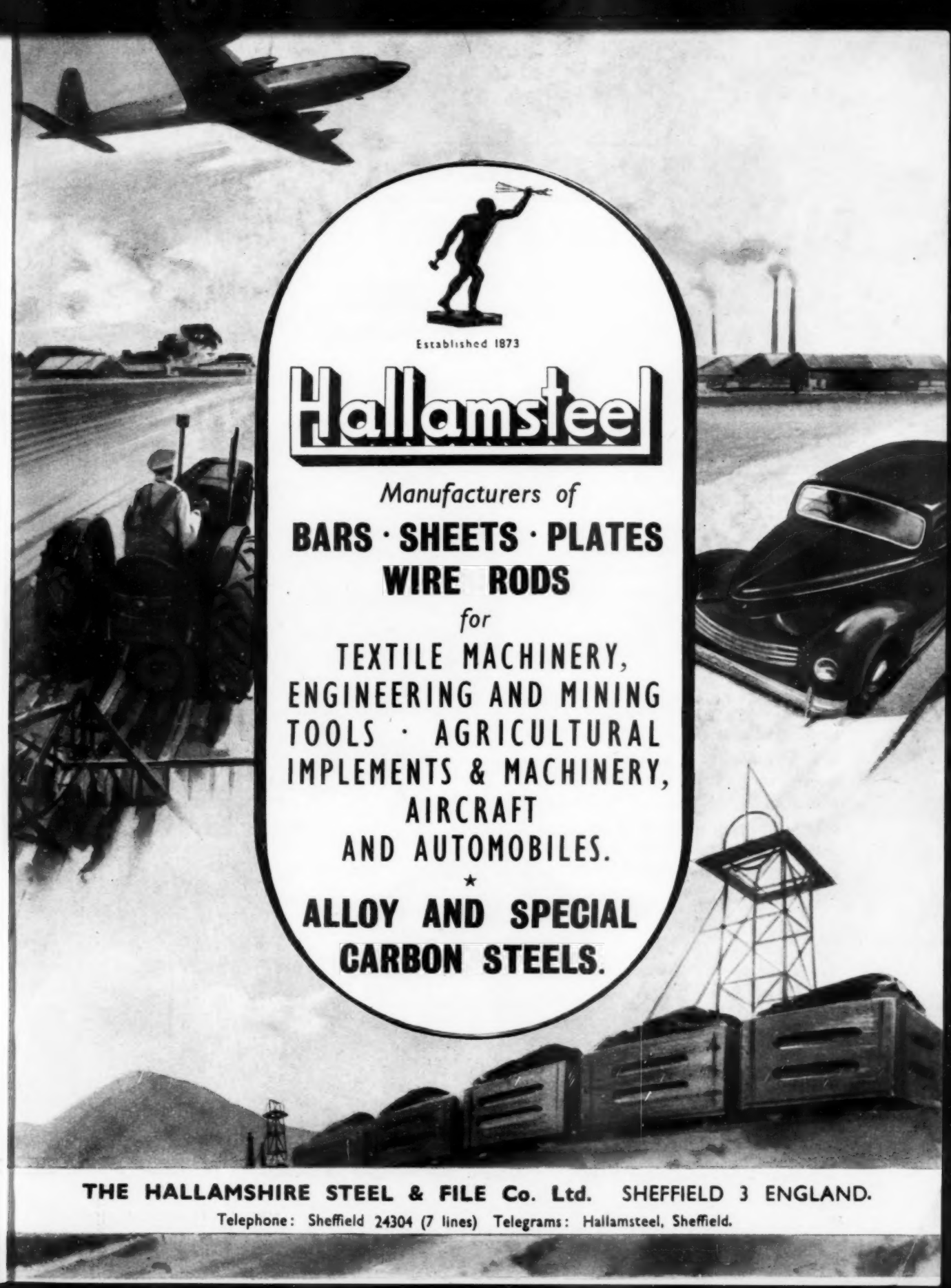

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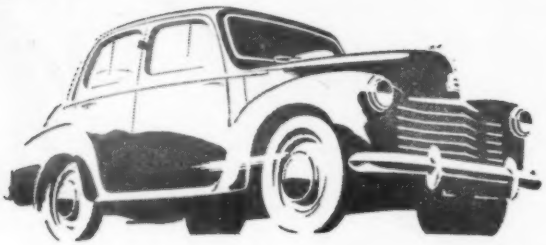
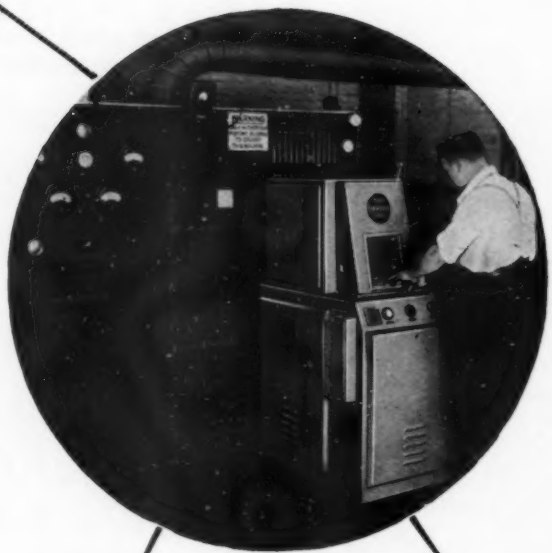
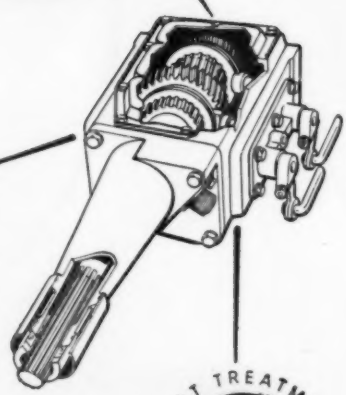
BIRLEC and the new Vauxhalls



The synchro-mesh gear box of the new Vauxhall cars employs a sliding sleeve with internal splines which take the brunt of the synchronising torque. For the local hardening of these splines, after final machining and without distortion of the sleeve, Vauxhall have installed this Birlec induction heating unit. This is just one of the tricky production heat treatment jobs handled regularly by specialised Birlec induction equipment.



For scale-free, distortionless, localised hardening as an automatic repetition process, Birlec induction heating is often the answer. Versatile units, installed direct in the production line, can be adapted for a range of generally similar work and can pay handsome dividends in quicker production, reduced grinding, cleaner finish and fewer rejects.



BIRLEC LTD • ERDINGTON • BIRMINGHAM 24

HEAT TREATMENT BIRLEC & MELTING FURNACES

In Australia: Birlec Limited, Sydney, N.S.W. *In Sweden:* Birlec Elektrougnar AB, Stockholm

SM/BI9a

MAZDALUX PROTECTED FLUORESCENT FITTING F.1115

Mazdalux Fitting, F.1115 with clear "Perspex" window. For use with 2 ft., 4 ft. and 5 ft. Mazda Fluorescent Lamps. (Illustration shows 2 lamp 5 ft. fitting).

FOR CORROSIVE ATMOSPHERES

This efficient and robust Mazdalux Fluorescent Fitting, F.1115, is completely resistant to smoke, fumes, dust and steam. Lamps, reflector and the interior of the fitting are protected and maximum lighting efficiency is maintained in locations where harmful elements are present in the atmosphere. Advice on installing all types of fluorescent lighting can be obtained from BTH Lighting Advisory Service, Bridle Path, Watford. Tel: 7701/8

MAZDA

MADE BY B T·H ENGLAND

FLUORESCENT LAMPS IN MAZDALUX FITTINGS

THE BRITISH THOMSON-HOUSTON CO. LTD., CROWN HOUSE, ALDWYCH, LONDON, W.C.2

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HIGH CARBON .004" TO .020" THICK
Our strip rolling plant has been laid down specially for producing bright cold rolled strip steel only in these thin sizes and high carbons. We do not manufacture soft strip of the deep drawing quality.
COLD ROLLED BRIGHT STEEL STRIP
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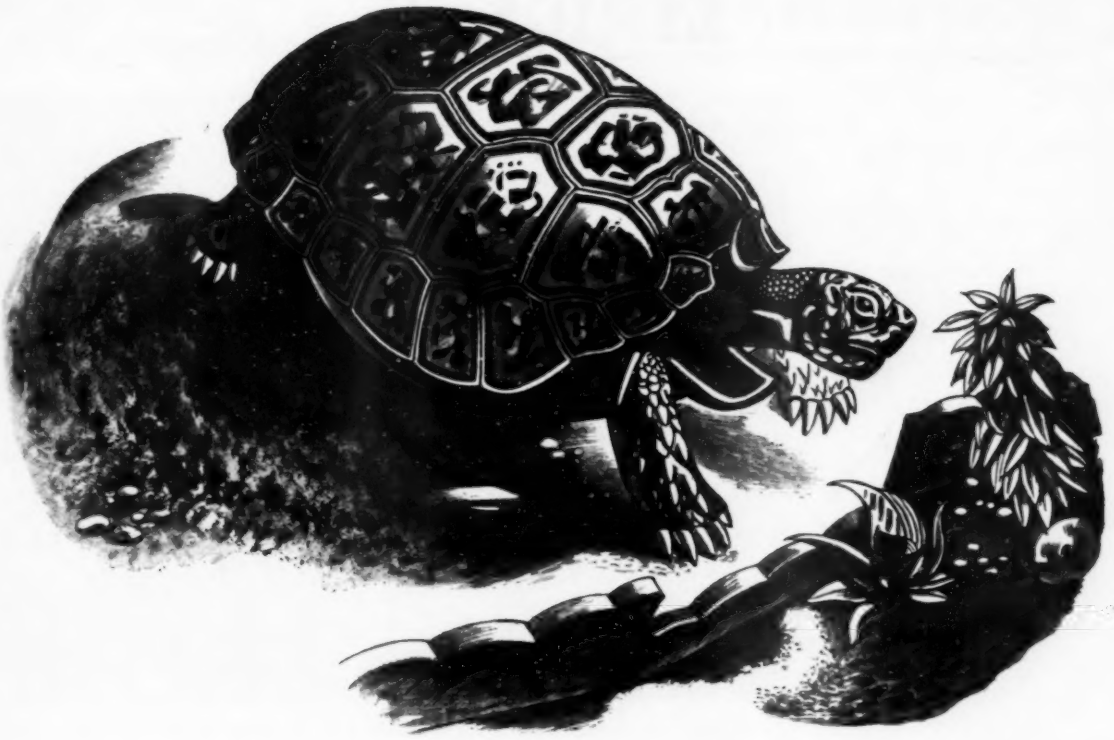

THE TORTOISE

grows its case slowly

The metallurgist obtains quick and accurate case depths by using

'CASSEL' 'RAPIDEEP' SALT BATHS

For details of 'Cassel' Heat-treatment Salts and
Salt Bath Furnaces consult:—

IMPERIAL CHEMICAL INDUSTRIES LIMITED
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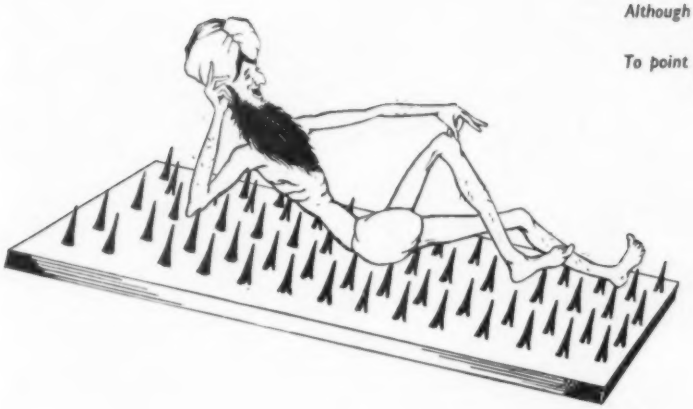
ICI

C.C.138

LIGHTWEIGHT **LYRICS** ·

NUMBER NINE

BEHOLD THE FAKIR, ON HIS NAILY BED,
Who often to himself has said :
" This is my own, my chosen spot ;
Thank heaven I don't weigh a lot !"



Although he has such queer ideas,
The fakir on his nails appears
To point a moral and make plain
That loss of weight is really gain !

Fakirs are famous for their toughness and durability, as well as for their modest weight. TJP aluminium alloys have these same virtues, plus a lot of others that please particular customers. For several years now PRIESTMANS' have specialised in aluminium alloys, and nothing else but aluminium alloys. Concentration has produced Perfection. There's the full range of standard specifications to choose from, but if you want something extra special for your very own use PRIESTMANS' will gladly co-operate in its production. Every consignment will be of uniform quality and true to original specification. To make sure of that we maintain our own chemical and physical laboratories for frequent, ruthless checks at every stage of production. For *certain* satisfaction specify " TJP ".

ALUMINIUM TPJ BRAND ALLOYS

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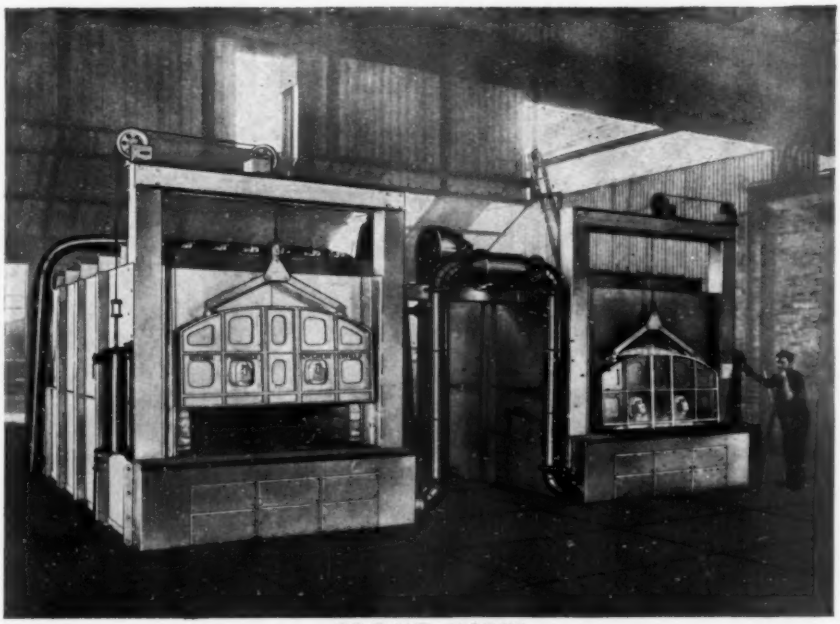
GAS FIRED FURNACES *in the* SHEET MILL



FRONT VIEW

Special Features

Uniform Slab Temperature

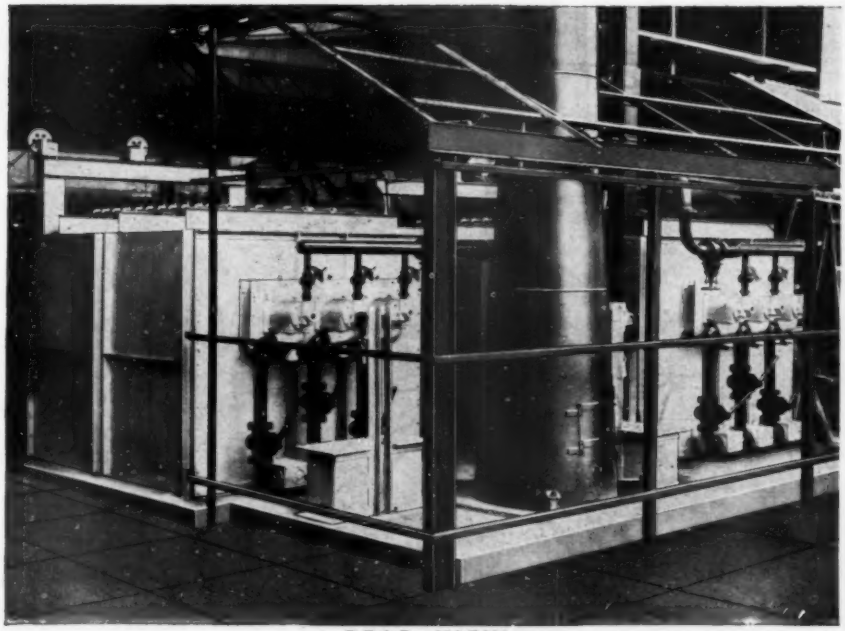
High Output

Production of Soft Scale easily removed on first pass

Low Gas Consumption

Ease of Control

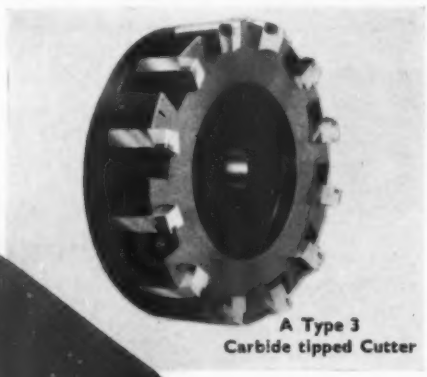
A pair of Sheet Mill Furnaces. Towns Gas Fired, one 6ft. × 6ft. and the other 6ft. × 11ft., either being capable of being used as a "hot" or "slow" fire, *i.e.* 750°C to 1250°C.



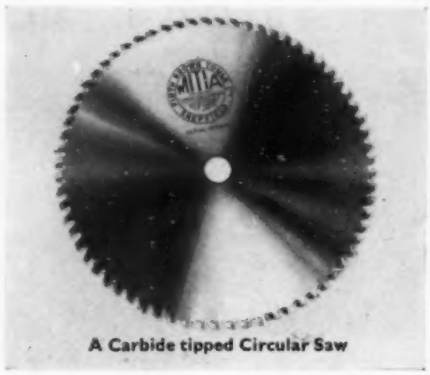
REAR VIEW

BRITISH FURNACES LTD., CHESTERFIELD

PERFECT MATERIAL · PERFECT SHAPE



A Type 3
Carbide tipped Cutter



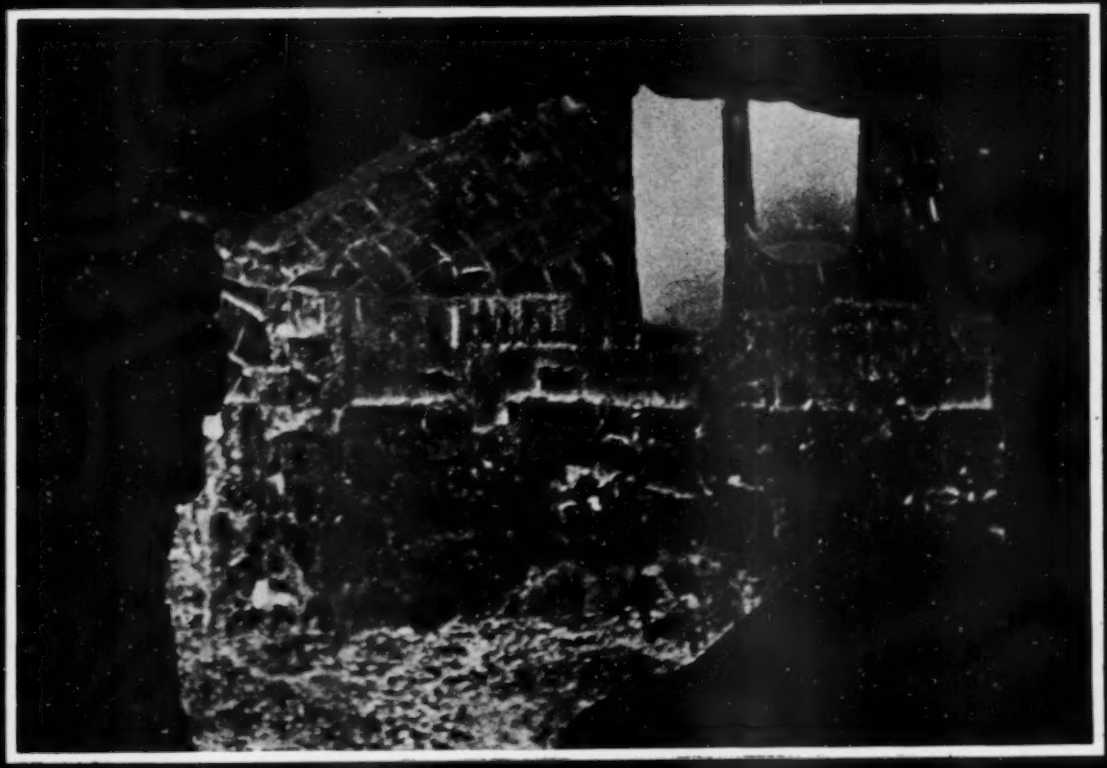
A Carbide tipped Circular Saw

A Carbide
tipped Reamer

"MITIA"
CARBIDE TIPPED TOOLS

FIRTH BROWN
TOOLS LTD. SHEFFIELD

a record life...



"Stein KM" (burned Chrome-Magnesite) bricks are giving consistently good service in side walls of basic electric furnaces. Photograph shows interior of a 10 ton furnace after 11 weeks' operation. Lining was 9" thick and bricks were jointed using steel sheets. May we send you further particulars?

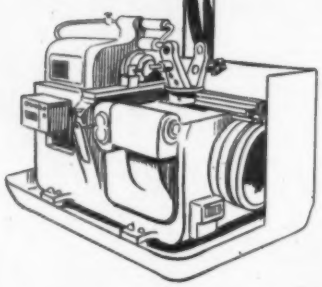
John G.
STEIN & Co. Ltd.

BONNYBRIDGE · SCOTLAND

Achievements in BRITISH ENGINEERING

A.E.C. MATADOR MARK III

Reproduced by courtesy A.E.C. Ltd., London



FRAPOL NEAT CUTTING OIL is used in the production of this notable example of British Engineering.

QUALITY PRODUCTS

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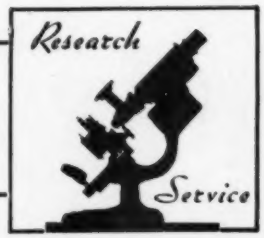
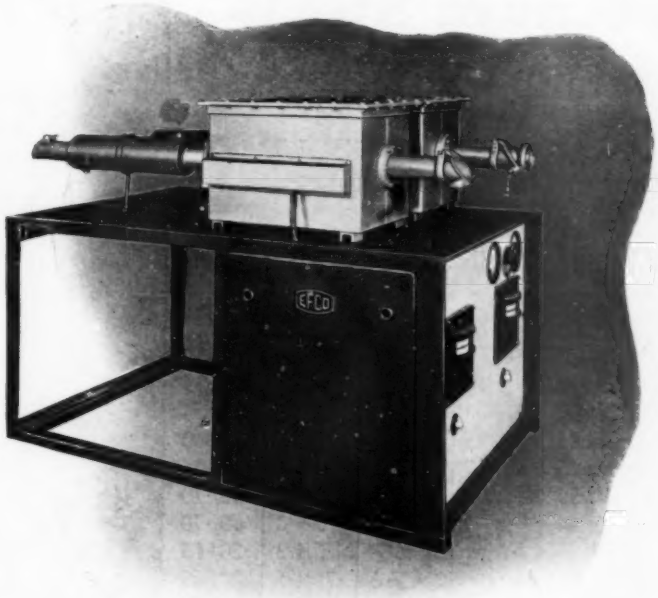
EDGAR VAUGHAN & CO. LTD

BIRMINGHAM 4 ENGLAND



EFCO HIGH TEMPERATURE MOLYBDENUM FURNACES

for Powder Metallurgy, Laboratory Work and General Heat Treatment at Temperatures up to 1700° C



COMPLETE SINTERING UNIT showing PREHEATING FURNACE for use at temperatures up to 1150° C and SINTERING FURNACE–Max. temperature 1700° C

THE design and construction of EFCO Molybdenum wound furnaces is based on many years experience in this class of work.

The winding of the tubes is unique resulting in a very long element life and the design allows of quick and easy replacement of tubes and elements.

Standard designs from 1 inch inside diameter tubes to 5 inches inside diameter are available.

EFCO also make muffle type furnaces with molybdenum windings suitable for use up to 1700° C

A FULL SIZE UNIT WILL BE ON SHOW AT STAND C 611, B.I.F. BIRMINGHAM

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Useful Molybdenum Steels

Data Sheet 1

SPECIFICATIONS AND COMPOSITIONS FOR GENERAL ENGINEERING PURPOSES

B.S. En No.	Type	C%	Mn%	Ni%	Cr%	Mo%
	FOR HARDENING AND TEMPERING					
13	Mn-Ni-Mo	·15/·25	1·4/1·8	0·4/0·7		·15/·35
16	Mn-Mo	·25/·40	1·3/1·8			·20/·35
17	Mn-Mo	·30/·40	1·3/1·8			·35/·55
19	1% Cr-Mo	·35/·45	·5/ ·8		·9/1·5	·20/·40
24	1½% Ni-Cr-Mo	·35/·45	·45/ ·7	1·3/1·8	·9/1·4	·20/·35
25	2½% Ni-Cr-Mo	·27/·35	·5/ ·7	2·3/2·8	·5/ ·8	·40/·70
26	2½% Ni-Cr-Mo	·36/·44	·5/ ·7	2·3/2·8	·5/ ·8	·40/·70
27	3% Ni-Cr-Mo	·25/·35	·7max.	3·0/3·75	·5/1·3	·20/·65
28	3½% Ni-Cr-Mo	·25/·40	·7max.	3·0/4·5	·75/1·5	·20/·65
29	3% Cr-Mo	·15/·35	·65max.	·4max.	2·5/3·5	·30/·70
30B	4¼% Ni-Cr-Mo	·26/·34	·4/ ·6	3·9/4·3	1·1/1·4	·20/·40
100	Low Alloy	·35/·45	1·2/1·5	·5/1·0	·3/ ·6	·15/·25
110	Low Ni-Cr-Mo	·35/·45	·4/ ·8	1·2/1·6	·9/1·4	·10/·20
160	2% Ni-Mo	·35/·45	·3/ ·6	1·5/2·0		·20/·35
	FOR CASE HARDENING					
34	2% Ni-Mo	·14/·20	·3/ ·6	1·5/2·0		·20/·30
35	2% Ni-Mo	·20/·28	·3/ ·6	1·5/2·0		·20/·30
39B	4¼% Ni-Cr-Mo	·12/·18	·5max.	3·8/4·5	1·0/1·4	·15/·35
320	2% Ni-Cr-Mo	·14/·20	·4/ ·7	1·8/2·2	1·8/2·2	·15/·25
325	Low Ni-Cr-Mo	·17/·22	·45/·65	1·5/2·0	·4/ ·6	·20/·30
	FOR NITROGEN HARDENING					
40A	3% Cr-Mo	·10/·20	·4/·65	·4max.	2·9/3·5	·40/·70
40B	3% Cr-Mo	·20/·30	·4/·65	·4max.	2·9/3·5	·40/·70
40C	3% Cr-Mo-V (V ·10/·30)	·30/·50	·4/ ·8	·4max.	2·5/3·5	·70/1·20
41	1½% Cr-Al-Mo (Al ·9/1·3)	·18/·45	·65max.	·4max.	1·4/1·8	·10/·25

CLIMAX MOLYBDENUM COMPANY OF EUROPE LIMITED

2 & 3 CROSBY SQUARE, LONDON, E.C.3

DOWN TO BEDROCK IN COSTING

The designer can choose from a bewildering variety of steel specifications.

The engineering alloy steels listed here will be found to give optimum strength and toughness at the most economical ultimate cost.

Remember that ultimate costs include not only the initial cost of steel, but also that of the subsequent treatment and machining. Molybdenum-containing steels score on all these points.

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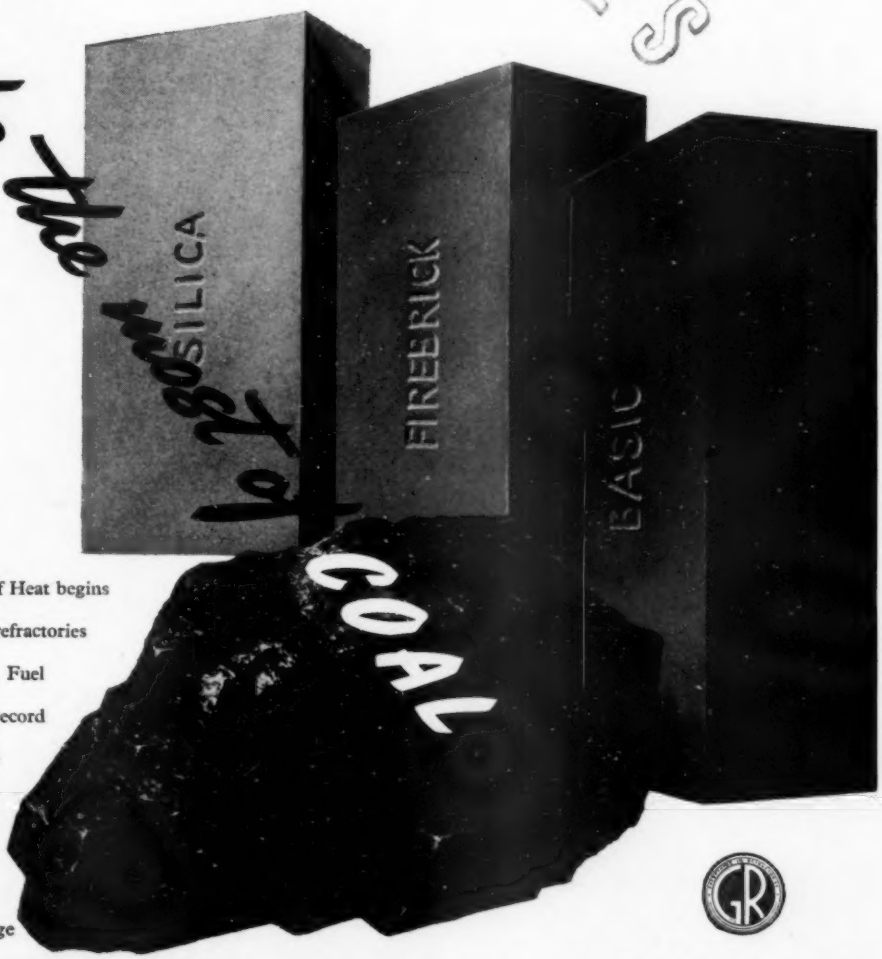
REFRACTORIES

Heat make the most of COAL



The conservation and control of Heat begins in the Furnace with the choice of refractories and their correct application. Fuel problems and the maintenance of record production outputs spotlight the need for *reliable* refractories. "G.R." represents a complete refractories industry inside one organisation. The "G.R." range of products is so wide that it includes the correct refractory for any type of furnace—a refractory which represents the last word in manufacture, development and research. If you have a difficult problem "G.R." engineers, supported by an efficient Technical Department, will advise and assist on the choice and application of their products. To make the most of fuel—it pays to consult "G.R."

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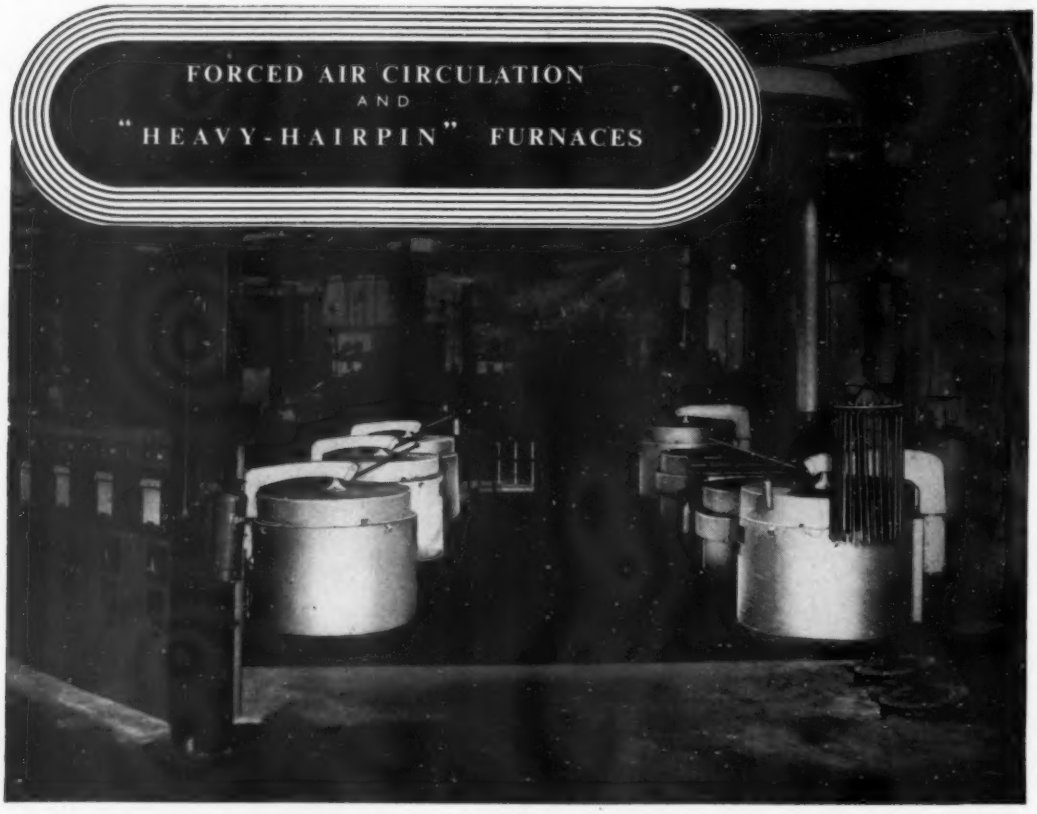
FURNACES FOR ALL HEAT-TREATMENT OPERATIONS



ELECTRIC WILD BARFIELD FURNACES

Besides rapid heating, the ideal plant for modern requirements must provide absolute uniformity of temperature with precise control of treatment in respect of both temperature and time. These features, together with easy operation, low running costs and safe working conditions, are inherent in Wild-Barfield furnaces. The photograph shows a mixed installation for the heat-treatment of automobile components. On the left are three special forced air circulation furnaces; on the right are two vertical " Heavy-Hairpin " furnaces. This layout, planned by Wild-Barfield to customer's requirements, shows how a complete plant for special purposes can be built up from standard furnaces working in conjunction with special equipment, thus avoiding the necessity for an entirely purpose-made plant.

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1949 IS THE 50th ANNIVERSARY OF THE DRIVER-HARRIS COMPANY

BACKGROUND TO ACHIEVEMENT

Hydro-Electric
POWER
Over two million horse-power is generated by the aluminium industry in hydro-electric plants in Northern Quebec, Canada.
Transport
RESOURCES
400 ocean freighters a year are needed to bring in the necessary raw materials to Port Alfred on the Saguenay River, Northern Quebec.
Laboratory
RESEARCH
The Aluminium Limited Group has three research laboratories, situated at Kingston, Ontario, Arvida, Northern Quebec, and Banbury, Oxfordshire.

One important feature of global geography is that the locations most suitable for large-scale production of virgin aluminium are literally "oceans apart". Here, the operative reason is the need for cheap and abundant hydro-electric power. Likewise, the principal raw materials of aluminium, such as bauxite and cryolite, are often found commercially in places far distant from the production centres. Transport by sea, land or both, is, therefore, a vast undertaking.

These difficulties overcome and the virgin metal produced, those responsible are faced with yet another problem. For pure aluminium, like pure gold, lends itself only to a limited number of uses. Before it can become sheet suitable for the builder or a high strength casting, aluminium must be alloyed with sister metals and then all manner of physical and mechanical conditions must be investigated before the properties of the metal can be established.

Thus, over the years, a great production organization also becomes an extensive research centre, responsible for seeking and maintaining the highest technological standards.

This, briefly, is the background to the achievements of the Aluminium Limited Group of Companies. Progress and development have gone hand in hand to meet the demands of a host of new applications of aluminium and aluminium alloys in every branch of trade and industry.

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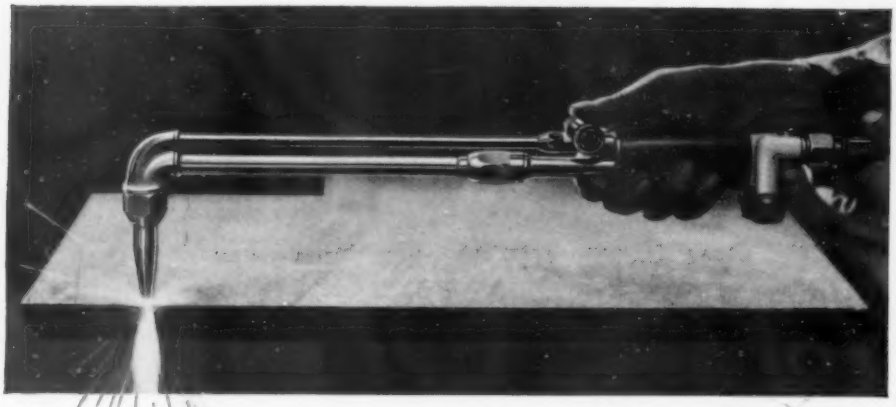

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Easy-grip plastic handle
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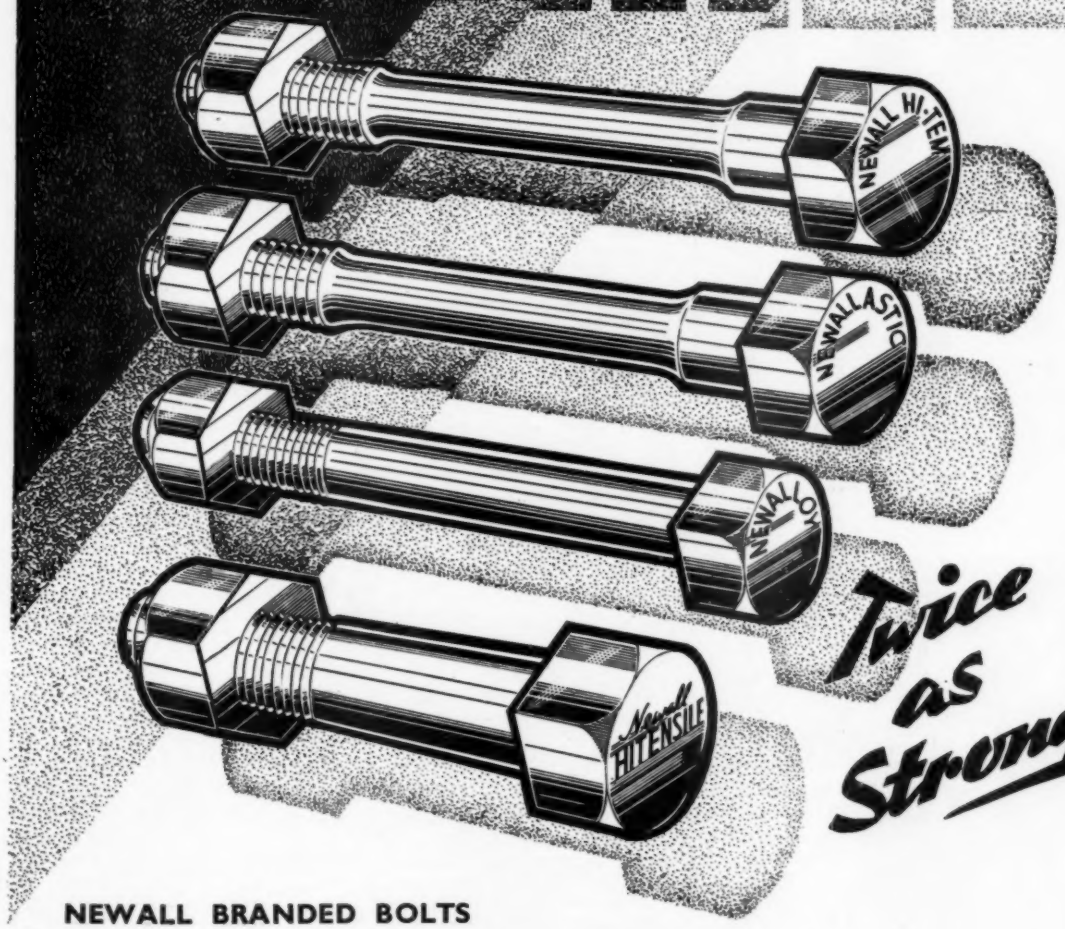

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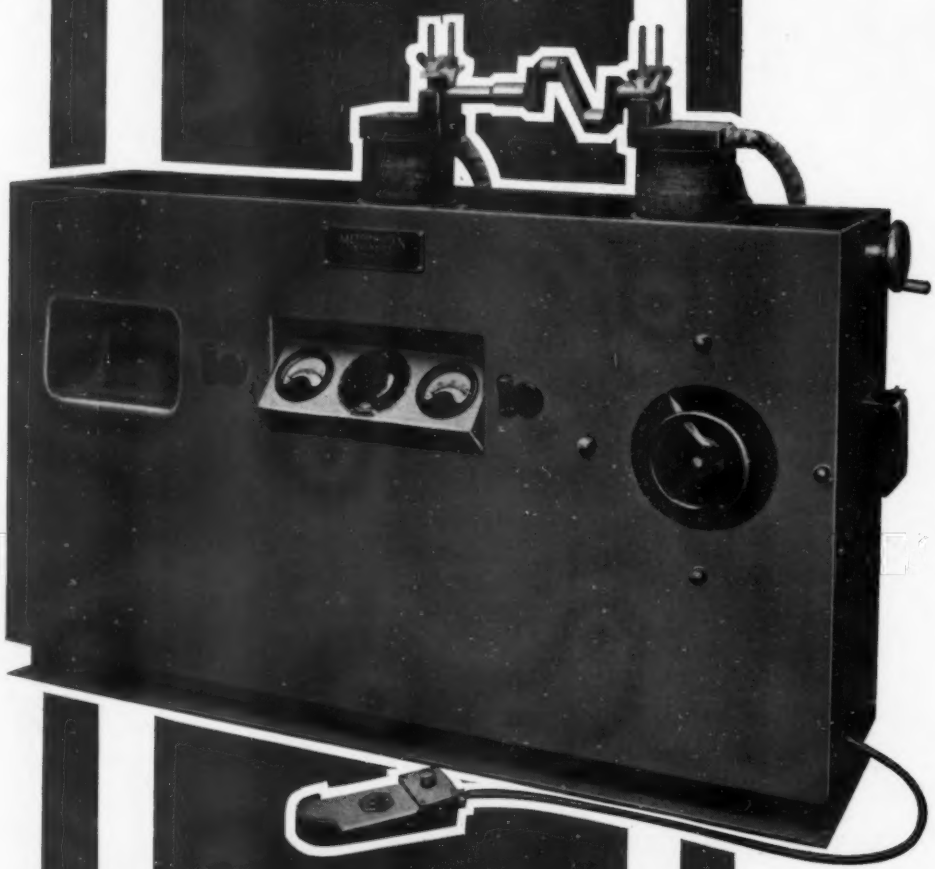

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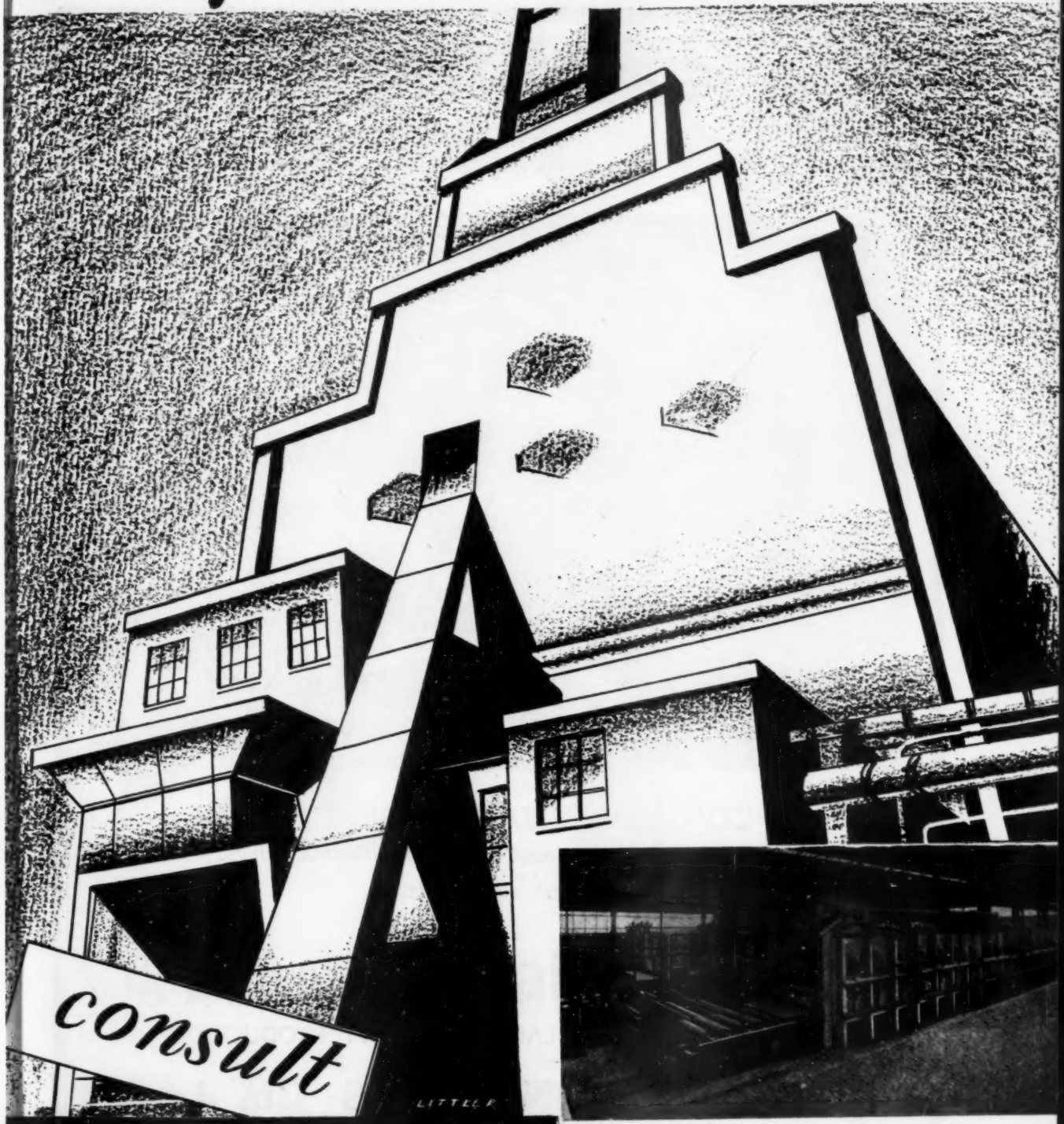

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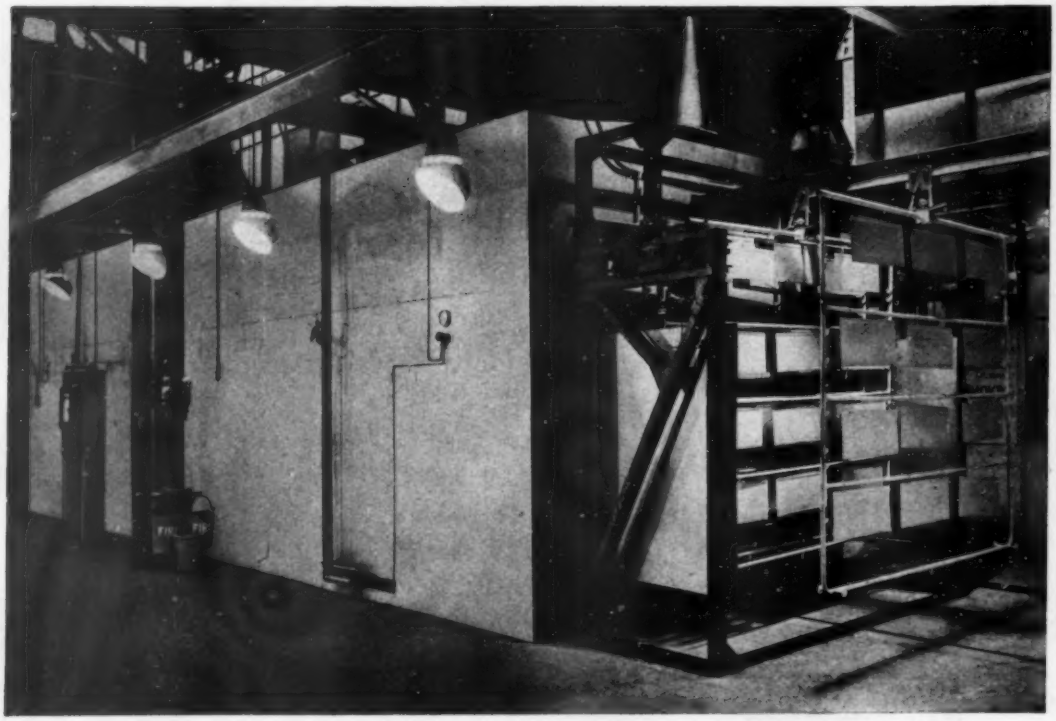

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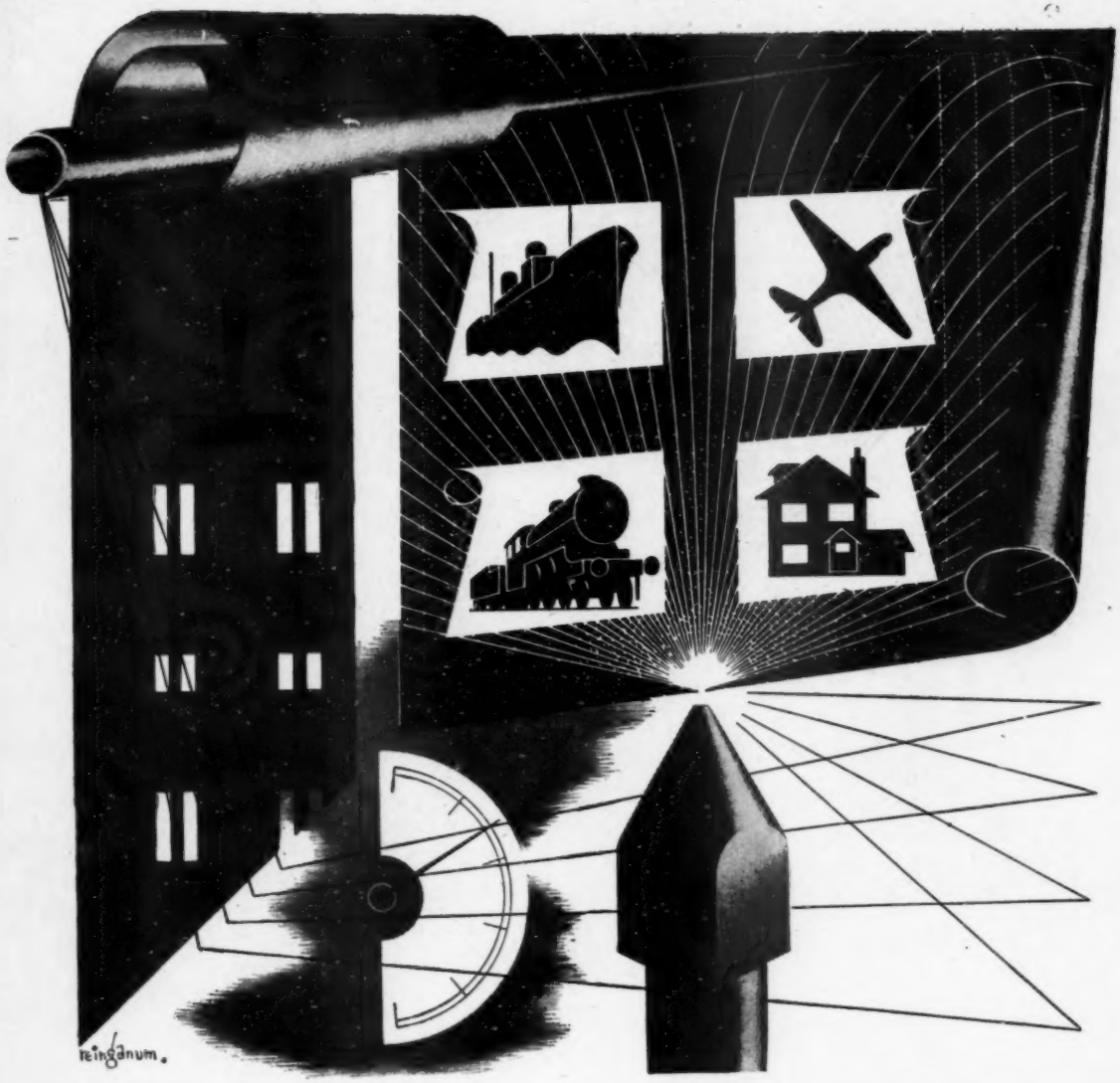

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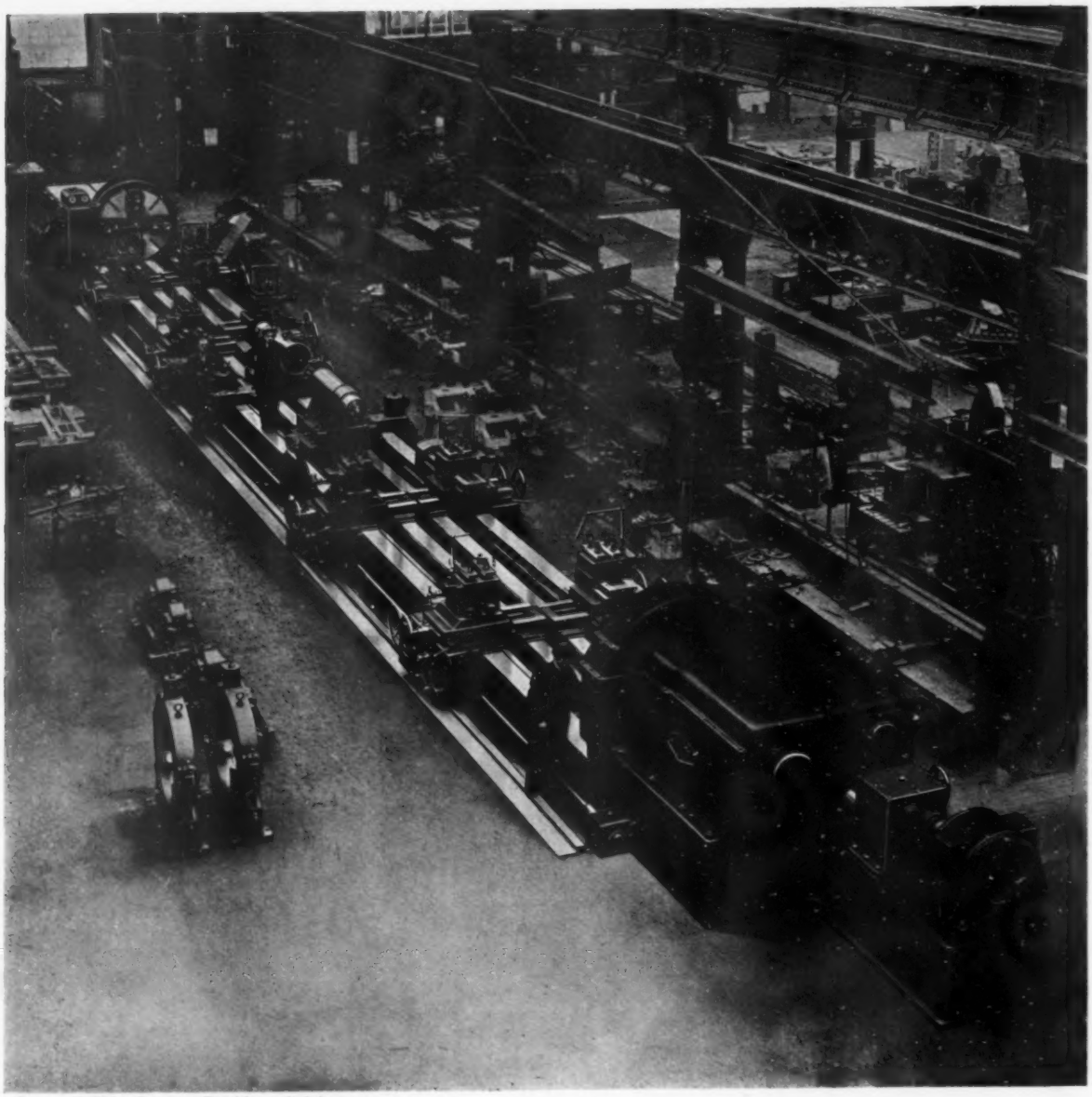

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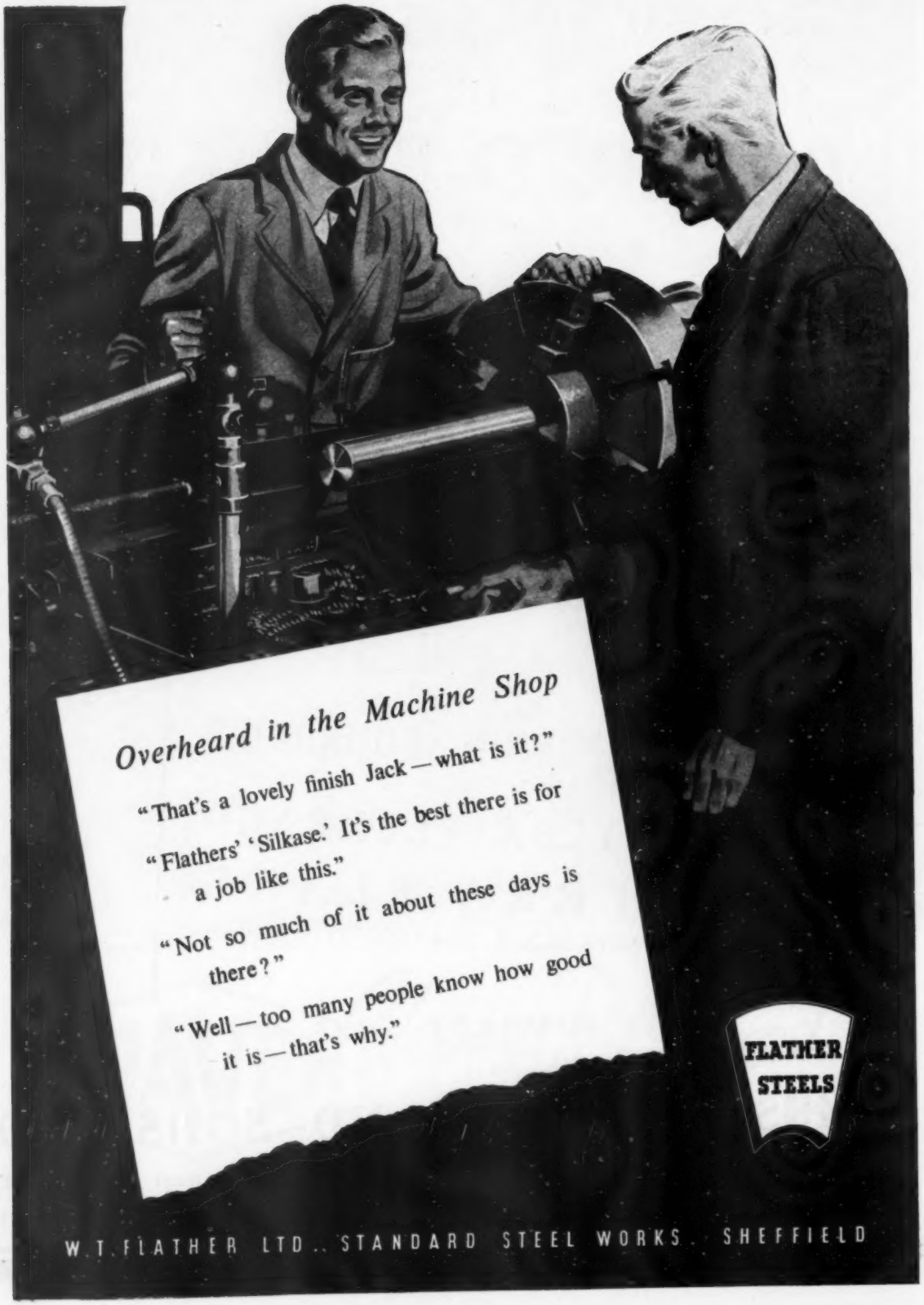
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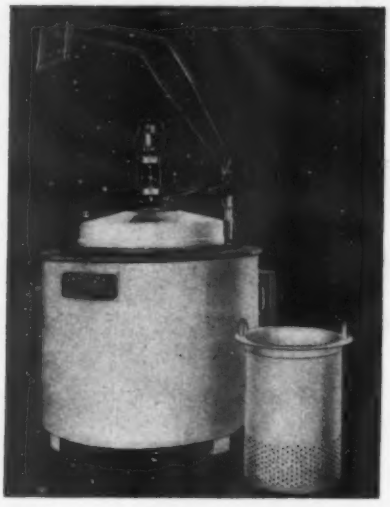

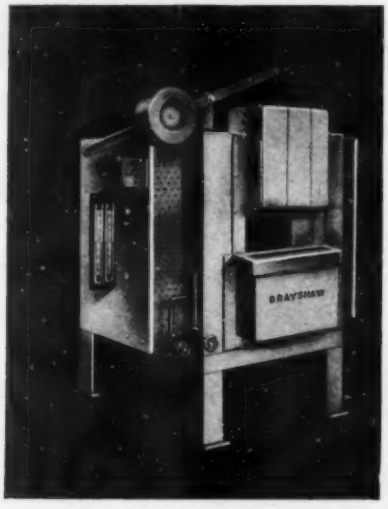

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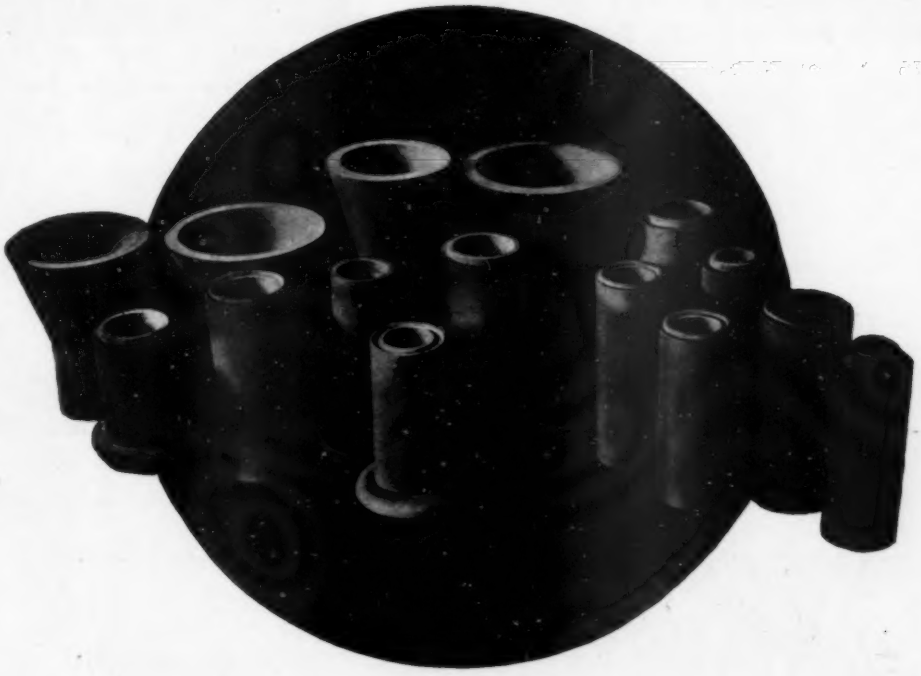

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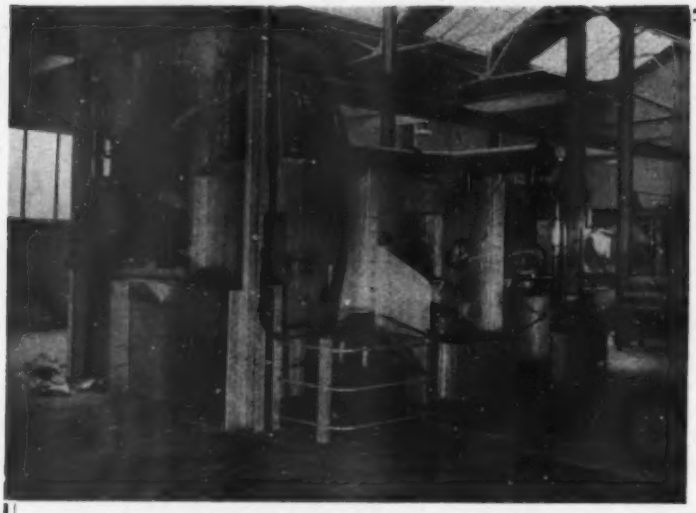

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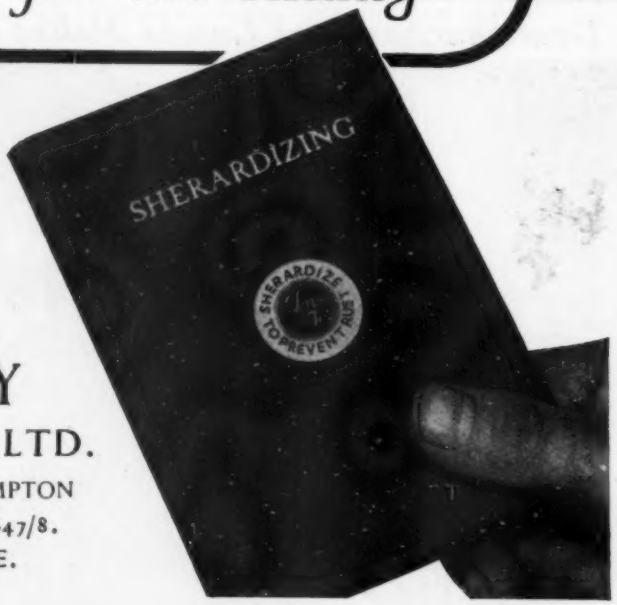

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Clearance: Vertical 40in., Radial 20in.

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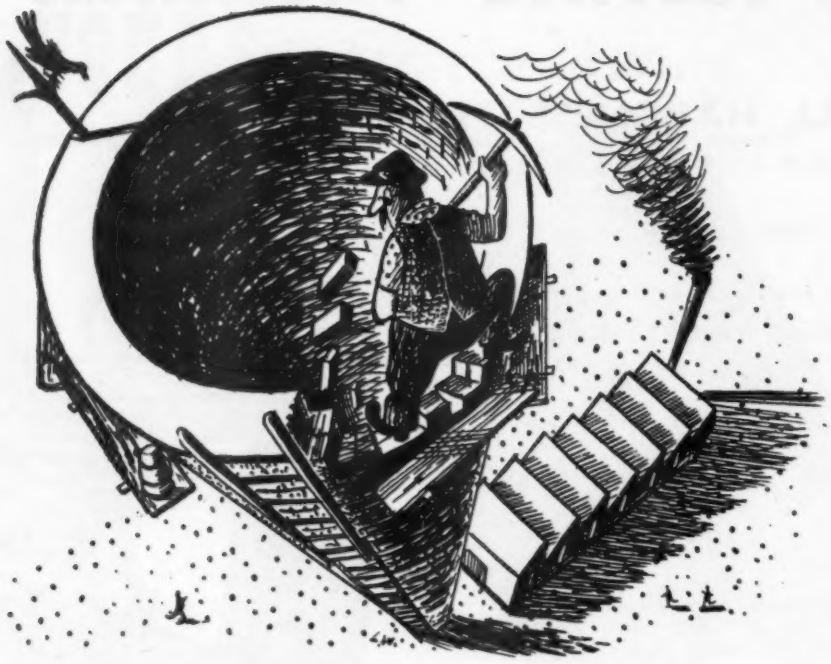

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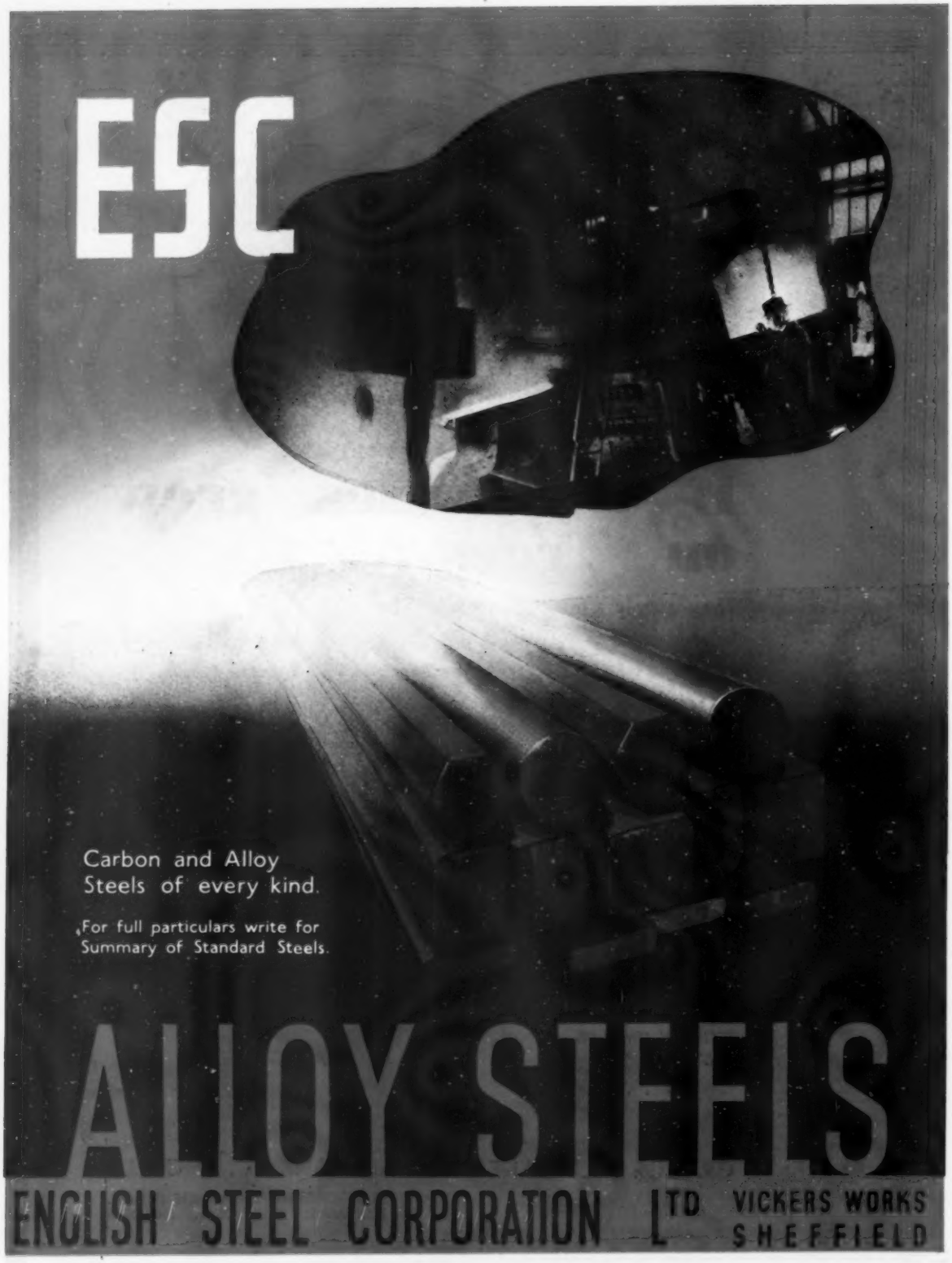
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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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The articles in this Journal are indexed in *The Industrial Arts Index*

Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 31, King Street West, Manchester, 3.
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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING THE "METALLURGICAL ENGINEER."

MARCH 1949 Vol. XXXIX No. 233

Steel Economy

SINCE the end of the war the primary concern of the iron and steel industry has been, and still is, efficiency in production. Practically every other industry depends upon its products for iron and steel and thus the period of transition from war- to peace-time activities was comparatively short; more than any other industry the iron and steel industry has been forced by circumstances to carry out delayed reorganisation and reconstruction, while at the same time endeavouring to maintain a high level of production. That it has been successful is now widely recognised; progressive managements and workers in the industry, in close co-operation, have repeatedly achieved production records to be quickly broken by the attainment of new high levels. Indeed the steel production for February, at the annual rate of 16,176,000 tons, is the highest rate of production ever achieved in this country in one month.

But the demands for steel far exceed the capacity of the steel industry and, although reorganisation and reconstruction are proceeding as rapidly as possible to meet these demands, it has long been recognised within the iron and steel industry that the various consuming industries can do much to relieve the position by making the most efficient use of the iron and steel available to them. In this way real economy can be effected. Designers must take advantage of the developments made by the application of scientific methods. Methods of accurate measurement are now provided by which metals and alloys may be tested; thus, knowing the type of qualities wanted in a metal, it is possible, by measurements on specimens, to say how far any particular metal fulfils these requirements. The properties in question may be strength, hardness, durability, machinability, resistance to corrosion, thermal conductivity, thermal capacity and expansion, magnetic permeability or retentivity, etc.

This aspect of the steel position has not been emphasised as much as it might have been, yet this problem of economy in the use of steel can be regarded as a vital and logical counterpart to the drive for increased production. Two years ago the Government appointed an official committee, the Steel Economy Committee, to attack the problem. This Committee has reviewed the possible fields of economies in the use of steel in building construction and in the constructional engineering industries and in an interim report has made recommendations on the ways and means by which savings may be effected.

The Committee recommends, wherever possible, the adoption of the new design specifications for steel and reinforced concrete. To this end it was decided that all construction involving the use of more than 25 tons of steel and licensed by the Ministry of Works must, wherever possible, comply with B.S.S. 449 relating to structural steel. This specification increases the basic permissible stress from 8–9 tons/sq. in. and the flexual stress to 10 tons/sq. in. Attention is directed to the considerable economies that can be effected in steel usage by the application of welding. Many of the more progressive engineering works have adopted the process but there is considerable scope for its extended use. The greater use of high tensile structural steels would effect considerable saving. A great deal of research has been devoted to the development of these steels, which have a permissible working stress of 13½–15 tons/sq. in. as against 10 tons/sq. in. for mild steel. In practise the saving varies between 15 and 25%. Cold rolled sections, such as angles, tees and channel sections, are much lighter than the normal hot-rolled sections and their use instead of hot-rolled sections results in steel economies of from 30–50%. It is suggested that further development in the production of cold-rolled sections for various branches of the engineering and manufacturing industries and for general building construction would assist both home and export trade. In this connection it is noteworthy that the Ministry of Works, in accordance with the recommendations of the Committee, is initiating suitable prototype work in connection with beams and rafters and roof trusses for building constructions using cold-rolled steel sections.

The Committee has given considerable attention to possible economies of steel in reinforced concrete construction and by the use of pre-stressed concrete. In reinforced concrete work where high tensile steels are used in tension, the economies amount to as much as 30% in favourable circumstances. It is claimed that there are fields of reinforced concrete construction where British standard mild steel could be used to better advantage, especially in pre-cast products subject to factory controlled operations. It is probable that the more extensive use of medium tensile, high tensile and cold-rolled high yield-point steels is restricted somewhat by supplies and designers may hesitate to base their plans on these qualities, but readjustment of supplies should not be difficult.

There are, of course, many other directions in which economy in the use of steel can be effected by making proper use of higher standards of performance. But steel economy is essentially a matter for the consumer and every effort should be made to see that the latest scientific advice is available to all who need it. Economy depends on design and in order that the most effective techniques may become available, a committee—the Professional Institutions Committee—has been formed to organise technical papers and discussions on steel economy with a view to exercising the economies to be derived from high performance specifications and more scientific methods of design.

While this aspect of economy in the use of materials is especially important in the case of steel because of its vital contribution to national economy, a full appreciation of developments in recent years of materials of construction would enable substantial savings in all metals and alloys.

Science and Industry

In order to encourage the application in metallurgical industry and research of known optical techniques, the British Iron and Steel Research Association is to hold a conference on May 9th and 10th at Ashorne Hill, Leamington Spa. The general chairman will be Mr. E. W. Colbeck of Messrs. Hadfields, Ltd.

The practical application of three techniques will be the subjects of the discussions, together with essential theoretical treatments, to describe each technique as a laboratory art. There will also be practical demonstrations throughout the conference.

The three techniques are: (a) phase contrast microscopy, (b) the multiple beam interference technique (c) the reflecting microscope.

Of these, apparatus for the first two is commercially available, and the third is being developed with the aid of a Nuffield grant.

The phase contrast microscope, which has been largely developed by Dr. Burch, at Bristol University, is already used to quite a large extent in Universities, particularly in biological work in which "transmission" technique can be employed with light shining through the specimens. In metallurgical work reflection technique must be used and by its means greatly increased contrast may be obtained to accentuate very small differences. It is thought that this could make a most useful tool, both for routine testing and in the pursuit of research.

The multiple beam interference technique has been developed by Professor Tolansky at Manchester University and the Royal Holloway College. This is essentially a research tool for studying surface topography and gives phenomenal magnification in depth, so that height changes of the order of 20 to 40 Angstrom units may be estimated.

The Burch reflecting microscope has also been developed at Bristol University, now with the aid of a Nuffield grant by means of which ten instruments are being manufactured. It gives the advantage of a large working distance, and can therefore be used for examining specimens maintained under particular conditions, for example at high temperatures. It has the further advantage that the instrument can be focussed with visible light before using ultra-violet or infra-red ray.

In this connection Dr. Bouwers is coming over from Holland to explain and discuss his modifications, which are available commercially.

Application to attend and for accommodation at Ashorne Hill should be made to the Metallurgy Division, B.I.S.R.A., 11, Park Lane, W.1.

Double-Decker Trains

An experimental train of double-decked coaches, with more seats per coach than has before been possible, is being considered by British Railways for use on the Southern Region lines between London and Dartford. A "mock-up" replica of what one of the coaches will look like when completed, was exhibited by the Railway Executive at Marylebone Station, London, recently.

A double-decker electric train would have 8 coaches with a total seating capacity of 1,016 seats, equivalent to a 31% increase in seating capacity over a normal 8-coach electric train consisting of 6 open vehicles and 2 compartment type vehicles. In other words, there will be 4 seats in a double-decker for every 3 in existing carriages.

By various means the railways have greatly intensified their capacity for handling passenger traffic at the peak hours, both with steam and electric traction. The double-decker train is now being considered as an alternative solution to costly major widening works.

Experts first examined the existing types of double-decker in other countries, including the U.S.A., but largely due to the fact that British platforms are higher and loading gauges are more restricted than those in most other countries, none of the existing types was practicable. However, the Chief Mechanical Engineer of the Southern Region has now produced a prototype which is being considered by the British Transport Commission on the recommendation of the Railway Executive.

In the "trailer" (non-motor) coaches there will be 6 double compartments, each with 11 seats on the lower deck and 11 seats on the upper. Thus one door leads to 22 seats and each coach will seat 132 people.

Owing to the close clearances of bridges and tunnels, the windows for the upper deck will be fixed. Electrically operated fans will provide constant ventilation in the upper part of the coach, while the doors and windows of the lower deck will be of the normal kind.

Strip-lighting over the seats will help those seated to read without interference fom the shadow of passengers standing or moving from one part of the coach to another. "Grab" handles will be carefully placed to assist movement between the two decks and to assist standing passengers in the lower deck.

Courses to Improve Teaching Technique

Three experimental refresher courses to improve the art of teaching among technical teachers are being arranged by the Ministry of Education this year. The courses are primarily intended for technical teachers who have not previously taken a course of teacher training. Local Education Authorities have been asked to release teachers for the courses and are also invited to make suggestions on the range of subjects which might be included in future courses.

The three courses are to be held at the Technical Teachers Training Colleges at Bolton, Huddersfield, and the N.W. Polytechnic, London. At Bolton the course will be for teachers of building subjects, at Huddersfield for teachers of engineering, and at the N.W. Polytechnic for teachers of commercial subjects. The first course is to be held in the summer. Only teachers with not less than two years' full-time teaching experience in Technical Colleges or Secondary Technical Schools will be eligible. Tuition will be free, but teachers will be expected to pay for their board and lodging. Accommodation will be arranged if required and in the case of hostels the cost will probably amount to £2 5s. per week.

Teachers wishing to attend one of the courses should, after obtaining the agreement of the employing authority, apply not later than March 26th, to the Director of the College they wish to enter.

Thos. W. Ward Ltd., Albion Works, Sheffield, inform us that they have taken over world sales distribution for Eldair Press Brakes and for the precision gauges manufactured by K. Emsley Ltd., Bradford.

Wards have also been appointed selling agents for Darling and Sellers 10½ in. centre lathes throughout the world, with the exception of Australia.

Magnesium Alloy Protection by Selenious Acid-Dichromate Solutions

By L. Whitby, M.Sc., Ph.D., F.R.I.C.

Although it has been known for many years that thin coatings of selenium, produced by immersion in an aqueous solution of selenious acid, confer a considerable degree of corrosion resistance on magnesium alloys, there has been no large scale use of them in this country. The standard selenious acid treatment suffers from the disadvantages that the fatigue strength is reduced and that on certain alloys the adhesion of the coating is poor. In this article, the author discusses the results of an investigation into the influence of sodium-dichromate additions to the selenious acid bath.

THE value of thin surface films of selenium for the protection against corrosion of magnesium-base alloys was reported in 1932.[1] It was then shown that the protective value of selenium, which was readily deposited as surface coatings by immersing the alloys in aqueous solutions of selenious acid at room temperature, compared favourably with that of chromate coatings.

Work in other countries[2] confirmed the value of selenium coatings, but although their use for the field repair of damaged chromate coatings has been accepted,[3] they have not been used directly on any large scale in this country. The disadvantages of selenium for protection, are generally associated with cost, odour, and the appreciable reduction in the fatigue strength of the alloy brought about by a selenizing treatment. In addition toxicity fears have also been raised, although elemental selenium is accepted by most authorities to be non-poisonous and selenium salt solutions are certainly less objectionable in many respects than the more widely used chromate solutions.

Two genuine disadvantages of selenium treatment by the action of selenious acid solutions are: (1) The appreciable surface attack on the metal, which reduces appreciably the fatigue strength of the latter; and (2) the poor adhesion of the selenium coatings to magnesium-manganese binary alloys of the type represented by sheet to specification D.T.D. 118.

The present work was carried out in an attempt to modify the original selenium process to produce increased protective value with less reduction in the fatigue strength and without the necessity of adopting variations in the bath composition according to the composition of the alloy being treated.

Preliminary experiments showed that additions of sodium dichromate to selenious acid solutions reduced the rate of attack of the latter on magnesium-base alloys to produce smooth, adherent, reddish coatings consisting largely of elemental selenium. Their protective value by salt-spray tests appeared to compare favourably with that of straight selenium coatings, produced from selenious acid solutions. Comprehensive experiments were consequently made with selenious acid/dichromate mixtures and the present communication describes the main results of this work.

EXPERIMENTAL

Test-pieces

Unless otherwise stated test-pieces consisted of 4×2 in. panels cut from rolled sheet in alloys to specifications D.T.D. 120A and D.T.D. 118 of thickness 18 S.W.G. gauge and 22 S.W.G. gauge, respectively. The compositions were 5·85% aluminium, 0·29% manganese, 0·1% zinc, 0·01% iron, and 1·58% manganese, 0·1% zinc, respectively.

Pretreatment consisted of removal of the chromate-pickle coating by scouring with pumice powder and water followed by pickling for 5 seconds in a 5% solution by volume of concentrated nitric acid in water.

Corrosion Test

The treated and weighed panels were suspended vertically by P.V.C. cord in a closed chamber containing mist of a 5% solution of sodium chloride in water, the condensate from which was allowed to run to waste. The mist was generated for 8 hours continuously during each of five consecutive days every week and for the remaining time the panels remained in the humid atmosphere of the chamber.

At the conclusion of the test, corrosion product was removed by the chromic-acid method previously described[4] and the panels were reweighed, the loss of weight being taken as a measure of the corrosion suffered.

RESULTS

Influence of Selenious Acid/Dichromate Ratio and Temperature

Preliminary experiments were made with specimens to D.T.D. 120A immersed for constant times of 15 minutes at room temperature or 5 minutes at boiling point in solutions in which the concentration of sodium dichromate varied from 1–10% and the concentration of selenium dioxide also varied from 1–10%. As reference standards similar specimens were treated by the 30-minute hot bath (bath (iii)) of specification D.T.D. 911 and by immersion for 15 minutes at room temperature in a 10% (W/V) solution of selenium dioxide (straight selenium treatment). All specimens, together with untreated (cleaned and pickled only) specimens, were

TABLE I.—INFLUENCE OF CONCENTRATION OF SEPARATE CONSTITUENTS AND OF TEMPERATURE VARIATION ON THE PROTECTIVE VALUE OF DICHROMATE/SELENIOUS ACID BATHS ON D.T.D. 120A ALLOY

% Sodium Dichromate	Temperature	% Selenium Dioxide Mean Loss of Weight mg./dm.²/day					
		1·0	2·0	3·0	5·0	7·0	10·0
1·0	Room (15 mins.)	62	36	45	68	70	87
1·0	100° C. (5 mins.)	23	63	87	110	114	120
2·5	Room (15 mins.)	58	51	51	40	69	80
2·5	100° C. (5 mins.)	19	34	66	81	78	90
5·0	Room (15 mins.)	118	59	40	59	73	75
5·0	100° C. (5 mins.)	27	19	21	39	52	77
7·5	Room (15 mins.)	96	60	44	79	81	89
7·5	100° C. (5 mins.)	21	18	17	25	33	45
10·0	Room (15 mins.)	99	70	72	78	69	96
10·0	100° C. (5 mins.)	38	43	28	28	41	50

Reference Standards :—Bath (iii) of D.T.D. 911 .. .. .. 58 mg./dm.²/day
10% SeO_3 15 mins. at room temperature .. .. 40 mg./dm.²/day
Blanks (cleaned and pickled only).. 306 mg./dm.²/day

then exposed in duplicate for 20 days to the salt-spray test. The results of these tests, expressed as the average loss of weight per square decimetre per day are recorded in Table I.

In Table II are recorded the results of similar tests with an alloy to D.T.D. 118, and in this case owing to the much higher intrinsic corrosion resistance thereof, compared with that of D.T.D. 120A, the salt-spray tests were prolonged to one year.

Influence of Time and Temperature

Having determined, at fixed times and temperatures of treatment, the influence of variations in the dichromate/selenious acid ratio, investigations were made on the influence of time of treatment at 100° C. within a limited range of concentration variations in the bath. The results, using an alloy to specification D.T.D. 120A, are recorded in Table III. A limited number of tests were also made on the effect of variation of both time of immersion and of temperature of the bath, between the limits of 10 and 30 minutes, and 50° and 100° C., respectively; also included in Table III are the results of a limited number of tests in which sodium dichromate in the solution was replaced with either potassium dichromate or chromic acid.

Operational Life of Bath

In order to investigate the operational life of a dichromate/selenious acid mixture, 500 ml. were prepared of a solution containing 7·5% (w/v) of sodium dichromate plus 3·0% (w/v) of selenium dioxide. In this volume of solution 500 panels of alloy to D.T.D. 120A were treated in pairs, each panel being 4 × 2 in., equivalent, therefore, to the treatment of a total surface area of approximately 500 sq. ft. in a gallon of solution. Treatment consisted of immersion of the panels in the solution at boiling point for 30 minutes. The pH of the solution was measured by glass electrode during the course of the treatments, and 2 specimens from each consecutive 10 treated were submitted to a gravimetric corrosion test by exposure to salt spray for 17 days. In this manner the protective efficacy of the bath was determined. The results are summarised in Table IV.

During the treatment the appearance of the coatings changed from a glossy reddish-brown on those specimens first treated to a golden-brown iridescence for the final specimens treated.

TABLE II.—INFLUENCE OF CONCENTRATION OF SEPARATE CONSTITUENTS AND OF TEMPERATURE VARIATIONS ON THE PROTECTIVE VALUE OF DICHROMATE/SELENIOUS ACID BATHS ON D.T.D. 118 ALLOY

% Sodium Dichromate	Temperature	% Selenium Dioxide Mean Loss of Weight mg./dm.²/day					
		1·0	2·0	3·0	5·0	7·0	10·0
1·0	Room (15 mins.)	0·087	0·093	0·112	0·138	0·164	0·193
1·0	100° C. (5 mins.)	0·141	0·133	0·132	0·216	0·229	0·251
2·5	Room (15 mins.)	0·078	0·091	0·095	0·114	0·145	0·180
2·5	100° C. (5 mins.)	0·103	0·122	0·119	0·127	0·157	0·182
5·0	Room (15 mins.)	0·067	0·100	0·095	0·126	0·137	0·126
5·0	100° C. (5 mins.)	0·073	0·128	0·087	0·115	0·124	0·122
7·5	Room (15 mins.)	0·067	0·098	0·108	0·110	0·112	0·134
7·5	100° C. (5 mins.)	0·095	0·108	0·115	0·139	0·106	0·126
10·0	Room (15 mins.)	0·076	0·101	0·120	0·118	0·118	0·132
10·0	100° C. (5 mins.)	0·120	0·092	0·104	0·125	0·124	0·128

Reference Standards :—Bath (iii) of D.T.D. 911 .. .. 0·073 mg./dm.²/day
10% SeO_3 for 1 min. at room temperature preceded by 10 secs. in 1% CrO_3 solution at 90° C. .. .. 0·109 mg./dm.²/day
Blanks (cleaned and pickled only) 0·127 mg./dm.²/day

TABLE III.—INFLUENCE OF TIME AND TEMPERATURE OF TREATMENT ON ALLOY TO D.T.D. 120A

Concentration Ratio % W/V Sodium Dichromate to Selenium Dioxide	Time of Immersion minutes	Temperature of Bath Mean Loss of Weight mg./dm.²/day			
		50° C.	75° C.	90° C.	100° C.
5·0 : 2·0	5	—	—	—	61
,, ...	10	—	—	—	29
,, ...	15	—	—	—	41
,, ...	30	—	—	—	30
5·0 : 3·0	5	—	—	—	48
,, ...	10	86	55	74	38
,, ...	15	188	85	45	41
,, ...	30	142	67	56	24
7·5 : 1·0	5	—	—	—	95
,, ...	10	—	—	—	66
,, ...	15	—	—	—	35
,, ...	30	—	—	—	20
7·5 : 2·0	5	—	—	—	87
,, ...	10	—	—	—	39
,, ...	15	—	—	—	53
,, ...	30	—	—	—	18
7·5 : 3·0	5	—	—	—	41
,, ...	10	84	58	58	33
,, ...	15	112	62	61	30
,, ...	30	122	34	79	21
7·5 : 3·0 (a)	5	—	—	—	66
,, (b)	5	—	—	—	69
,, (c)	5	—	—	—	268
7·5 : 5·0	5	—	—	—	40
,,	10	—	—	—	79
,,	15	—	—	—	51
,,	30	—	—	—	53

Reference Standards :—Bath (iii) D.T.D. 911 .. .. .. 100 mg./dm.²/day
10% SeO_3 solution, 15 minutes at room temperature .. .. .. 73 mg./dm.²/day
Blanks (cleaned and pickled only) 305 mg./dm.²/day

Notes :—(*a*) Above, $Na_2Cr_2O_7.2H_2O$ replaced with $K_2Cr_2O_7$.
(*b*) Above, $Na_2Cr_2O_7.2H_2O$ replaced with *equivalent* weight of CrO_3.
(*c*) Above, $Na_2Cr_2O_7.2H_2O$ replaced with equal weight of CrO_3.

Storage Life of Bath

Panels, each 4 × 2 in., of alloy to D.T.D. 120A were treated in quadruplicate in (i) a freshly made solution of the 7·5/3·0 composition as above, and in (ii) a solution as (i) above, prepared 6 months previously and exposed to the atmosphere in an open 600 ml. parallel side glass beaker. Evaporation during the period of storage was balanced by a twice-weekly addition of distilled water to restore the solution to its original volume of 500 ml. In all cases the treatment consisted of immersion in the solution for 30 minutes at boiling point. The results of corrosion tests on the specimens are recorded in Table V.

Dimensional Change of Specimens and Thickness of Coating

Micrometer measurements made on flat panels of alloy to D.T.D. 120A before and after treatment for 10 minutes and 30 minutes in a boiling solution of 7·5% (w/v) of sodium dichromate plus 3% (w/v) of selenium dioxide showed a decrease in thickness due to the 10-minute treatment of 0·00005 in. for each face, and an increase in thickness of 0·00005 in. for each face after 30 minutes' treatment.

The mean loss of weight of 4 × 2 in. panels treated as above, after removal of the coating by immersion in a 20% (w/v) of chromic anhydride at boiling point, was

TABLE IV.—EFFECT OF CONTINUED USE OF THE BATH ON PROTECTIVE VALUE OF RESULTING COATINGS ON ALLOY TO D.T.D. 120A

No. of Panels Treated	Equiv. sq. ft. Surface per Gallon	pH of Solution	Mean Loss of Weight after Corrosion Test mg./dm.²/day
2	2	1·72	62
30	30	2·32	94
40	40	2·61	76
50	50	2·87	99
70	70	3·42	83
100	100	5·26	130
150	150	5·82	132
170	170	5·90	128
200	200	6·00	146
220	220	6·05	112
250	250	6·05	145
270	270	6·12	122
300	300	6·12	116
320	320	6·14	153
350	350	6·17	140
370	370	6·17	153
400	400	6·21	170
410	410	6·21	113
470	470	6·22	230
500	500	6·26	103
Blanks (no surface coating)	—	—	432

equivalent to 0·0218 g. per square decimetre of surface after 10 minutes' treatment and 0·1322 g. per square decimetre of surface after 30 minutes' treatment. On the assumption that the coating consists mainly of the red amorphous form of selenium (see later section) of specific gravity 4·3, the coating thickness is approximately 0·00005 cm. (0·000002 in.) after 10 minutes' treatment and 0·0003 cm. (0·000012 in.) after 30 minutes' treatment.

TABLE V.—INFLUENCE OF OPEN STORAGE OF THE BATH SOLUTION ON ITS PROTECTIVE EFFICIENCY

Bath	Loss of Weight mg./dm.²/day	
	Individual	Mean
New	118 104 115 151	122
Stored for six months without use	92 102 98 146	109
Blank specimens (no surface coating)..	372 347	359

Electrolytic Treatment

Following the successful results by simple immersion treatments in the dichromate/selenious acid solutions, it was decided to investigate the effects of anodic treatment of the metal in the 7·5% sodium dichromate, 3% selenium-dioxide bath, with time, temperature and current density variations. The solutions were held in 3 litre glass vessels with cathodes of graphite. For these tests alloy sheet to D.T.D. 120A was used and for the corrosion tests comparison was made with similar specimens treated by the straight immersion treatment in the same solution, the selenious acid immersion treatment, bath (iii) of D.T.D. 911 and with cleaned and nitric acid pickle treatment. In all cases duplicate specimens each 4 × 2 in. were used. The results of the tests are summarised in Table VI.

TABLE VI.—ANODIC TREATMENT OF ALLOY TO D.T.D. 120A IN DICHROMATE/SELENIOUS ACID BATH
Corrosion Test : Salt Spray for 12 days

Anodic Current Density (amps./ft.²)	E.M.F. (volts)	Time (mins.)	Temp.	Mean Loss of Weight after Corrosion Test mg./dm.²/day	Anodic Current Density (amps./ft.²)	E.M.F. (volts)	Time (mins.)	Temp.	Mean Loss of Weight after Corrosion Test mg./dm.²/day
3	0·3	2	18° C.	224	5	1·2	5	75°	131
"	"	3	"	153	"	"	10	"	84
"	"	5	"	88	8	1·5	1	"	143
"	"	10	"	86	"	"	2	"	70
5	0·6	1	"	208	"	"	3	"	78
"	"	2	"	138	"	"	5	"	91
"	"	3	"	130	"	"	10	"	68
"	"	5	"	95	3	0·7	1	80° C.	73
"	"	10	"	153	"	"	2	"	53
8	1·3	1	"	237	"	"	3	"	81
"	"	2	"	115	"	"	5	"	77
"	"	3	"	81	"	"	10	"	80
"	"	5	"	107	5	1·1	1	"	136
"	"	10	"	55	"	"	2	"	126
15	2·5	1	"	123	"	"	3	"	74
"	"	5	"	74	"	"	5	"	127
"	"	10	"	56	"	"	10	"	83
"	"	15	"	77	10	1·5	1	"	144
"	"	20	"	78	"	"	2	"	64
25	3·4	1	"	137	"	"	3	"	119
"	"	5	"	70	"	"	5	"	61
"	"	10	"	72	"	"	10	"	66
"	"	15	"	83	3	0·8	1	100° C.	97
"	"	20	"	87	"	"	2	"	93
50	5·5	1	"	123	"	"	3	"	78
"	"	5	"	121	"	"	5	"	89
"	"	10	"	110	"	"	10	"	100
"	"	15	"	83	5	1·5	1	"	100
"	"	20	"	94	"	"	2	"	104
3	0·3	1	30° C.	166	"	"	3	"	68
"	"	2	"	116	"	"	5	"	79
"	"	3	"	99	"	"	10	"	121
"	"	5	"	103	8	1·8	1	"	89
"	"	10	"	122	"	"	2	"	73
5	1·5	1	"	139	"	"	3	"	87
"	"	2	"	143	"	"	5	"	60
"	"	3	"	117	"	"	10	"	38
"	"	5	"	152	15	2·0	1	"	94
"	"	10	"	141	"	"	2	"	67
8	1·6	1	"	122	"	"	10	"	62
"	"	2	"	85	"	"	15	"	53
"	"	3	"	96	"	"	20	"	49
"	"	5	"	85	25	2·6	1	"	82
"	"	10	"	115	"	"	5	"	47
3	0·5	1	75° C.	106	"	"	10	"	49
"	"	2	"	102	"	"	15	"	51
"	"	3	"	80	"	"	20	"	71
"	"	5	"	99	50	3·6	1	"	90
"	"	10	"	94	"	"	5	"	66
5	1·2	1	"	85	"	"	10	"	79
"	"	2	"	64	"	"	15	"	72
"	"	3	"	99	"	"	20	"	92

Reference Standards :—30 minutes' immersion without current in solution (as above) at boiling point .. .. .. 66 mg./dm.²/day
Bath (iii) of D.T.D. 911 .. .. .. 81 mg./dm.²/day Blanks (no surface treatment) .. 479 mg./dm.²/day

Composition of Coating

The coating produced by immersion in the boiling dichromate-selenious acid solutions was of a glossy reddish-brown appearance, firmly adherent, and changing colour to a metallic grey on heating to 120° C. for a few minutes. This suggested the presence in the coating of a high proportion of elementary red selenium, but confirmation of this supposition by chemical analysis was difficult owing to the thin layer present on the metal (see previous section) and the difficulty of removing it either mechanically or by dissolution. X-ray diffraction photographs were taken on several samples of coated metal, but in each case no diffraction patterns could be obtained. Chemical analyses of the solutions used for the deposition of the coatings, before and after treatment of the metal therein, showed that during the coating process the selenium content of the solution decreased appreciably, whereas the dichromate content remained comparatively constant. Thus 40 ml. of a solution containing 7·5% (w/v) of $Na_2Cr_2O_7 2H_2O$ plus 3% (w/v) of SeO_2 were used to treat a total surface area of 751 square centimetres of an alloy to D.T.D. 120A; the treatment consisted of immersion of the metal for 30 minutes in the boiling solution. Chemical analyses of the used solution made up to its original volume, then showed a total selenium and chromium content corresponding to 1·92% (w/v) of SeO_2 and 6·4% (w/v) of sodium dichromate, respectively, equivalent to a proportional removal from the solution of 77 parts of selenium and 12 parts of chromium. Stripping of films on alloy to D.T.D. 120A by immersion in sodium-hydroxide solution produced a yellow colour in the latter with the parent metal surface clean and bright. Analysis of the solution and loss of weight of the metal showed that in a film weight of 100, there were 57 parts of selenium and 22 parts of chromium, the latter present in part as chromate since the solution gave a strong diphenylcarbazide reaction.

TABLE VII.—INFLUENCE OF SELENIUM-DICHROMATE SURFACE TREATMENT ON FATIGUE STRENGTH OF MAGNUMINIUM 166 ALLOY

Surface Treatment	Test No.	Stress Tons/in.²	Cycles to Fracture × 10^6
None	D.17	± 9·0	0·300
,,	D.65	± 8·0	2·722
,,	D.71	± 7·5	4·411
,,	D.28	± 7·25	11·930
,,	D.42	± 7·00	100*
Selenium	D.27	± 8·0	0·060
,,	D.39	± 7·0	0·306
,,	D.15	± 6·0	0·287
,,	D.26	± 5·75	13·800
,,	D.24	± 5·5	104·767*
Selenium-Dichromate	D.18	± 9·0	0·074
,,	D.67	± 8·0	0·696
,,	D.34	± 7·5	0·461
,,	D.69	± 7·25	0·257
,,	D.40	± 7·00	115·808*

* Specimen Unbroken

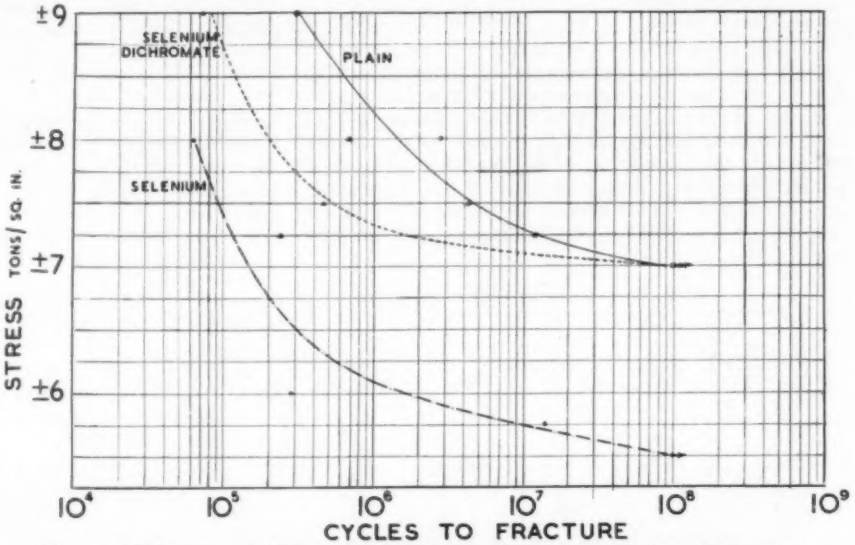


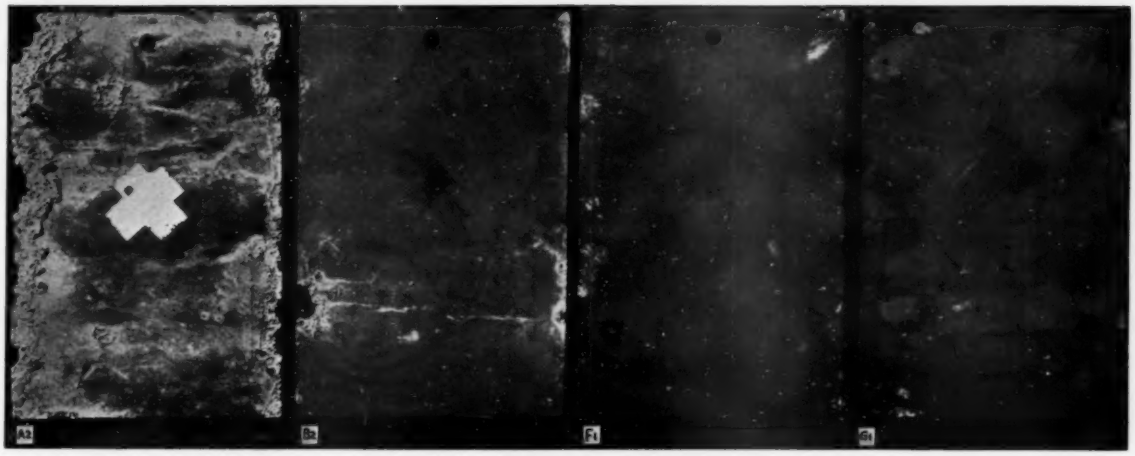
Fig. 1.—Influence of selenium and selenium dichromate surface treatments on the fatigue resistance of "Magnuminium 166" (D.T.D.88B).

Influence of Selenium-Dichromate Treatment on Fatigue Endurance Limit

Extruded 1 in. diameter Magnuminium 166 alloy bars (composition: 4·25% aluminium, 0·02% zinc, 0·10% manganese) were machined and mirror finished by hand longitudinally to give test-pieces of 0·400 in. diameter, 0·59 in. fillet radius with 4·29 in. moment arm. They were subjected to a rotating bending fatigue test, with single point loading at 2,300–2,900 reversals per minute. The specimens were divided into three sets—viz.: (1) Without surface treatment; (2) with standard selenium treatment (15 minutes' immersion at room temperature in a 10% (w/v) solution in water of selenium dioxide);

TABLE VIII.—RESULTS OF ACCELERATED WEATHERING TESTS ON PAINTED MAGNESIUM ALLOYS WITH VARIOUS PRETREATMENTS

Alloy Spec.	Pretreatment	Paint System	Cycles of Accelerated Weathering	% Surface Corroded	Adhesion
D.T.D. 118	None.	Stoving	4	15 (from edges)	Fair
,,	D.T.D. 911, bath (iii)	,,	,,	5 ,,	Poor
,,	Dichromate-Selenium, 10 mins.	,,	,,	10	Poor
,,	Do. rubbed.	,,	,,	10	Fair
,,	Do. 5 mins., not rubbed.	,,	,,	5	Good
,,	Do. do., rubbed.	,,	,,	4	Good
,,	Do. 2 mins., not rubbed.	,,	,,	60	Poor
D.T.D. 120A	None.	,,	,,	75	—
,,	D.T.D. 911 bath (iii).	,,	,,	20 (from edges)	Good
,,	Dichromate-Selenium, 5 mins.	,,	,,	35 ,,	Good
,,	Do. 15 mins.	,,	,,	30 ,,	—
,,	Do. do., rubbed.	,,	,,	25 ,,	Good
,,	Do. 30 mins. not rubbed.	,,	,,	30 ,,	Good
,,	Do. do., rubbed.	,,	,,	15 ,,	Good
D.T.D. 118	None.	Air-drying	12	5 ,,	Poor
,,	D.T.D. 911 bath (iii).	,,	,,	None	Poor
,,	Selenium.	,,	,,	,,	Poor
,,	Dichromate - Selenium.	,,	,,	,,	Poor
D.T.D. 120A	None.	,,	,,	20 (from edges)	Poor
,,	D.T.D. 911 bath (iii).	,,	,,	5 ,,	Fair
,,	Selenium.	,,	,,	2 ,,	Poor
,,	Dichromate - Selenium.	,,	,,	1 ,,	Good



Pre-treatments (left to right) : none, bath (iii) D.T.D.911, selenium-dichromate, straight selenium.

Fig. 2.—Results of 12 cycles of accelerated weathering (D.T.D.517) on air-dry painted alloy to D.T.D.120A.

and (3) selenium-dichromate treatment (immersion for 30 minutes at boiling point in a 7·5% (w/v) solution of sodium dichromate plus 3·0% (w/v) of selenium dioxide). The results are recorded in Table VII and illustrated in Fig. 1.

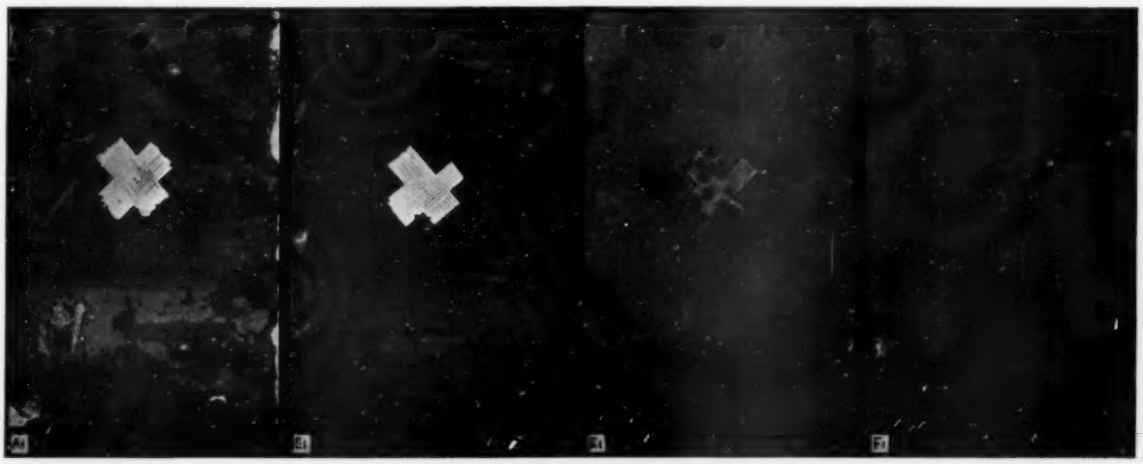
Use of Selenium-Dichromate Coatings as Paint Bases

Panels, each 6 × 4 in., of alloys to D.T.D. 118 and D.T.D. 120A were pretreated by the selenium-dichromate method and by other means for comparison and coated with one coat of a low-bake medium oil-length drying-oil-modified alkyd resin varnish, pigmented with carbon black, or with an air-drying system consisting of two coats of UP4 (a tung-oil phenolic resin vehicle with zinc chromate in the pigment) followed by one coat of a matt brown nitro-cellulose finish to Specification D.T.D. 308. The painted panels were tested[5] by submission to the accelerated weathering cycle of Specification D.T.D. 507.[6] The stoving finish was submitted to 4 cycles of the weathering test and the air-drying system to 12 cycles thereof. Following the exposure cycles the paint was assessed for adhesion by means of a "window" test[7] and the percentage amount of the paint surface showing corrosion product was visually estimated. The results are recorded in Table VIII and some are illustrated in Figs. 2, 3, 4, and 5.

DISCUSSION

Influence of Selenious Acid/Dichromate Ratio

Table I shows that for alloy to D.T.D. 120A treated at room temperature in solutions of fixed sodium-dichromate content, increase in the selenious acid content of the solutions from 1–10% causes an initial increase followed by a decrease in the protective value against salt spray of the resulting coatings. At all concentrations of sodium dichromate tested the maximum protective value of the coatings appears to be gained when the selenium dioxide content of the solution is

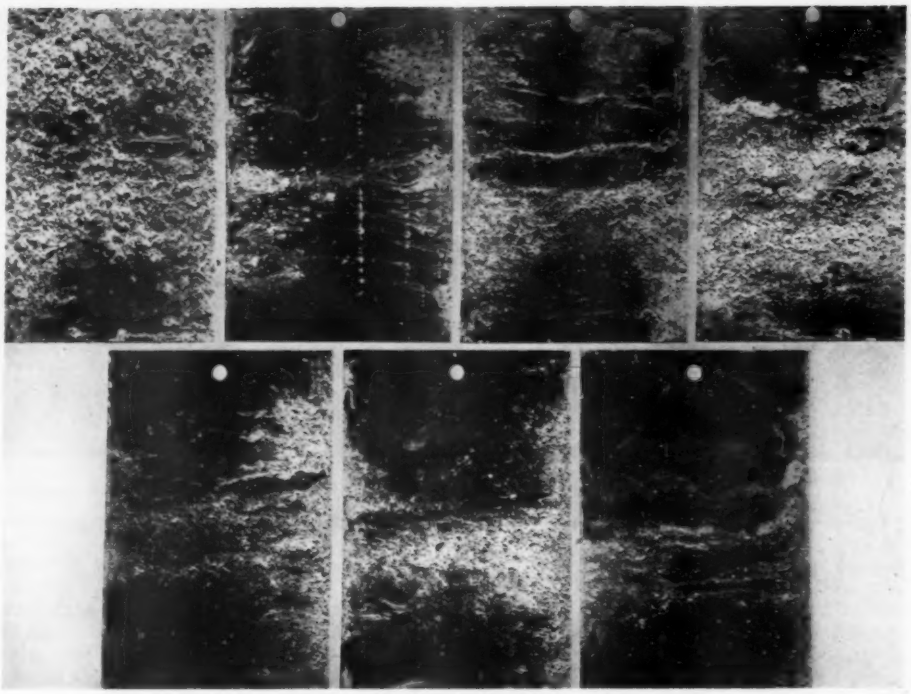


Pre-treatments (left to right) : none, bath (iii) D.T.D.911, straight selenium, selenium-dichromate.

Fig. 3.—Results of 12 cycles of accelerated weathering (D.T.D.517) on air-dry painted alloy to D.T.D.118.

between 2 and 5%, the optimum between these limits being dependent upon the actual dichromate concentration.

With solutions at boiling point, and with a sodium-dichromate content of either 1% or 2·5%, increase of the selenium dioxide content from 1%-10% causes a steady decrease in the protective value of the coatings. On the other hand, with sodium dichromate contents of 5, 7·5 or 10% there is an indication, as with the tests at room temperature, of a maximum in the protective value of the coatings when the selenium dioxide content of the solutions is between 2 and 5%. With the 5–10% dichromate contents the protective value of the coatings was invariably considerably better from boiling solutions than by deposition from solutions at room temperature. The best results appeared to be obtained by the use of a solution at boiling point containing 7·5% of sodium dichromate and 3% of selenium dioxide.



Pre-treatments (left to right) : (1) none, (2) bath (iii) D.T.D.911,(3) selenium-dichromate 5 mins., (4) selenium-dichromate 15 mins., (5) selenium-dichromate 15 mins. rubbed, (6) selenium dichromate 30 mins., (7) selenium-dichromate 30 mins. rubbed.

Fig. 4.—Results of 4 cycles of accelerated weathering (D.T.D.517) on stove-painted alloy to D.T.D.120A.

In the case of alloy sheet to D.T.D. 118 the protective value of the coatings is shown in Table II to be decreased with increase in the selenium-dioxide content of the baths, but the error level here is high owing to : (i) The extremely high resistance to corrosion of this alloy compared with that of the alloy to D.T.D. 120A, and (ii) the fact that the removal of the coating by the chromic acid used for the dissolution of corrosion product accounts for a substantial proportion of the total loss of weight. With alloy to D.T.D. 120A a high degree of protection is given by the best of the dichromate-selenious acid treatments, compared with that given by bath (iii) of D.T.D. 911, whereas with alloy to D.T.D. 118, there is *apparently* but little protection gained by the application of dichromate-selenious acid treatment. It may be noted that in no case was any odour noted from these coatings comparable to that noted with straight selenium coatings.

Influence of Time and Temperature

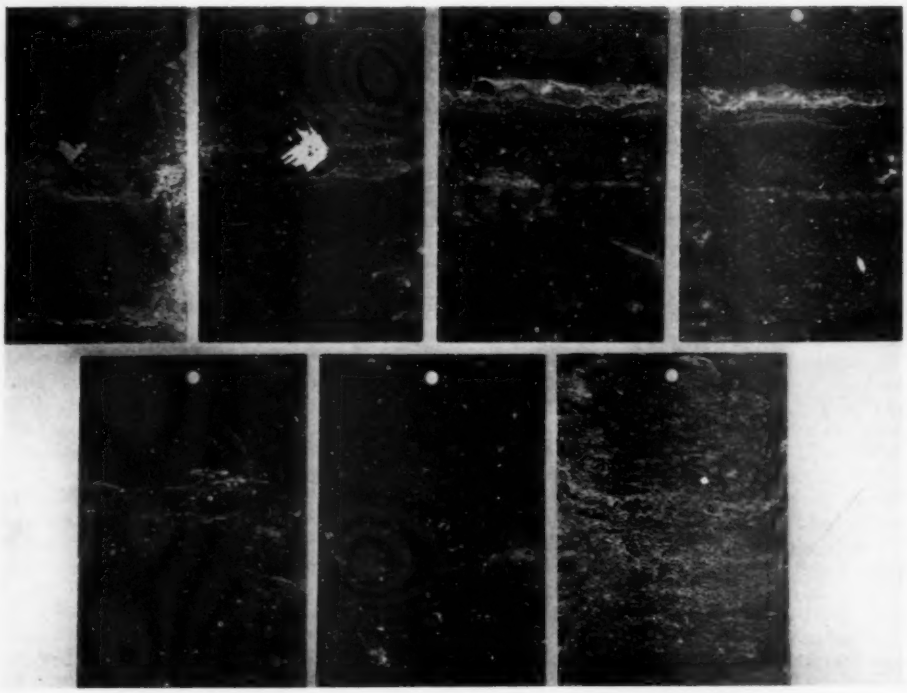
Apart from the experiments the results of which are recorded in Tables I and II, which show differences between the effects of solutions at room temperature and at boiling point, the further experiments recorded in Table III give more precise information on the effects of intermediate temperatures of the solutions, and also show the influence of variations in the times of treatment of the metal. With boiling baths there is a marked improvement in the protective value of the coatings (on alloy to D.T.D. 120A) when the time of treatment is extended from 15–30 minutes, with the exception of the one solution tested with a selenium-dioxide content as high as 5%. In the latter case the best results were obtained with 5 minutes' immersion only, increase in this time causing a decrease in the protective value of the coatings. It had previously been shown, however (Table I) that the optimum content of selenium dioxide is normally below 5%.

With all solution concentration ratios tested and with all times of immersion tested the protective value of the coatings was best from solutions at boiling point, compared with solutions at 50°, 75°, or 90° C.

Tests on the replacement of sodium dichromate with potassium dichromate or with chromic acid, also recorded in Table III, showed that such substitution decreased the protective value of the coatings.

Life of Baths

The operational life of a bath of the optimum composition shown by the above experiments (7·5% of sodium dichromate plus 3% of selenium dioxide) is apparently remarkably prolonged, as shown by Table IV. The scatter in results with duplicate specimens is high, but nevertheless, it is clear that a marked degree of protection is still given when some 500 sq. ft. of metal surface area (D.T.D. 120A) have been treated per gallon of solution. Such surface area/volume ratio, without revival additives to the bath, is exceptional. Table IV



Pre-treatments (left to right) : (1) none, (2) bath (iii) D.T.D.911, (3) selenium-dichromate 10 mins., (4) selenium-dichromate 10 mins. rubbed, (5) selenium-dichromate 5 mins., (6) selenium-dichromate 5 mins. rubbed, (7) selenium-dichromate 2 mins.

Fig. 5.—Results of 4 cycles of accelerated weathering (D.T.D.517) on stove-painted alloy to D.T.D.118.

indicates that no marked reduction in the protective value of the coatings is likely to occur until some 70 sq. ft. of surface area have been coated for each gallon of solution thus rendering the process one of considerable economy of material. No experiments have yet been made on revival of used baths by the addition of selenium dioxide, to reduce the pH to its original value, but no doubt this operation could readily be carried out.

No deterioration of the bath was detected on exposure to the atmosphere for six months, and apparently the solution thus remains stable on open storage, as shown by the results recorded in Table V.

Dimensional Change of Articles

Negligible dimensional change of alloy to D.T.D. 120A is caused by the treatment, an increase in thickness of approximately 0·00005 in. occurring after the standard treatment of 30 minutes' immersion in a solution at boiling point of 7·5% (w/v) of sodium dichromate plus 3% (w/v) of selenium dioxide.

Electrolytic Treatment

The results of a considerable number of experiments on the anodic treatment of metal to D.T.D. 120A in dichromate-selenious acid baths at various temperatures and for various times are recorded in Table VI. In general it is clear that no advantage accrues from anodic treatment, as compared with simple immersion in the baths without current.

Composition of Coatings

The composition of the coatings is not known definitely but it is clear from the various tests to which they have been subjected that both amorphous selenium and chromium (as chromate) are present, most of the coating consisting of selenium. It is also not known whether or not an interfacial layer of magnesium selenide is present (thought to be responsible, in the case of normal selenium coatings, for their self-healing properties),[1] since the protective value of the present coatings may be largely associated with the passivifying action of the chromate present, which would probably prevent interfacial combination between the magnesium and the selenium. It is, indeed, clear from the fatigue tests that the presence of dichromate in selenious acid solutions prevents the latter from attacking the magnesium-alloy surface in such a manner that the fatigue resistance of the specimen is reduced, as occurs by the action of selenious acid solutions free from dichromate additions. In addition, the dichromate reduces the rate of attack and the coatings are considerably thinner, although more protective, than those resulting from immersion in straight selenious acid solutions.

Influence of Selenium-Dichromate Treatment on Fatigue Strength

Although only one particular alloy was used for the investigation of the influence of selenium-dichromate treatment on the fatigue strength of the alloy, it is clear from Table VII and Fig. 1 that the latter treatment shows to considerable advantage over the simple selenious acid dip in this respect. Thus where straight selenious treatment reduced the endurance limit, compared with the untreated metal, by approximately 21%, the selenium-dichromate treatment was considerably less active in this respect.

Selenium-Dichromate Coatings as Paint Bases

The durability of paint coatings is largely associated with the maintenance of their adhesion to the substrate and however effective a paint coating may be in terms of impermeability to moisture, resistance to weathering and the like, loss of adhesion will enable paint/substrate interfacial reactions such as corrosion to occur with consequent peeling, flaking or blistering of the paint. The presence of a corrosion-inhibitive material, such as zinc chromate, in the primer will frequently improve

durability when inherently poor adhesion occurs, but failure often follows mechanical damage and the highest degree of protection is undoubtedly associated with close and continuous contact between the paint and the metal.

In the case of magnesium alloys, surface conversion coatings, not necessarily of themselves possessing protective value, have proved of immense value in increasing the degree of adhesion of paint coatings and so providing systems of high protective merit.

Poor adhesion of paint coatings is often not evident before they are aged, but on ageing contractile forces are developed and tend to lift the paint from the surface painted. For this reason conclusions drawn from so-called adhesion tests on recently applied paint coatings are often misleading and in the present work the painted panels were submitted to accelerated weathering tests before adhesion was investigated.

In general it was found that with both the stoving and the air-drying paints adhesion was less effective on alloy to D.T.D. 118 than on alloy to D.T.D. 120A. On alloy to D.T.D. 118 adhesion of the stoved paint was considerably improved by decreasing the pre-treatment time in the dichromate-selenium bath to 5 minutes and then rubbing off the thin, loosely-adherent, surface layer before applying the paint. The behaviour of panels so treated compared most favourably not only with that of panels subjected to similar pre-treatment without rubbing off the loose surface deposit, but also with that resulting from the usual chromate pre-treatment of bath (iii) of D.T.D. 911.

In the case of the air-drying paint system on alloy to D.T.D. 118 the zinc chromate-bearing primer reduced corrosion considerably compared with that resulting from the non-corrosion-inhibitive stoving paint, but adhesion was poor in all cases. Removal of loose matter from the pre-treatment coatings was, however, not investigated before applying the air-drying paint system.

On alloy to D.T.D. 120A, the air-drying paint system behaved better in respect both of adhesion and of the development of corrosion, when applied over the coating resulting from the standard (30 minute) selenium-dichromate treatment than when applied over the chromate coating resulting from bath (iii) of D.T.D. 911. With the stoving paint, adhesion was good on alloy to D.T.D. 120A with all pre-treatments investigated, but the standard 30-minute selenium-dichromate treatment resulted in the least corrosion.

With straight selenium coatings covered with paint and subjected to corrosion tests it was previously observed[1] that selenium apparently migrates locally from the metal/paint interface to the surface of the paint. It was considered that this phenomenon is due to hydrolysis of magnesium selenide and re-deposition of selenium by oxidation of hydrogen selenide, at pores in the paint coating. Such migration of selenium, although filling a useful function, often results in the formation of small blisters in the paint coating, each coloured red from selenium. It may be noted that a similar phenomenon was observed in the present tests with straight selenium coatings, but not with the selenium-dichromate treated panels, where apparently the dichromate prevents the formation of magnesium selenide, thought to be responsible for selenium migration.

Containers and Fume Exhaust

For the present tests the selenium-dichromate solutions were held in glass containers, which would not be practicable for large-scale use. Experiments have shown that the solutions involved affect neither mild steel nor aluminium, and it is possible to boil panels of these metals therein without apparent surface change. It is evident, therefore, that for large-scale use containers of either mild steel or aluminium could be employed without difficulty.

Spray does not arise from the solutions during operation, but in view of the known toxicity of dichromate fume and the alleged toxicity of selenium compounds, fume exhaust as normally used for chromium plating or chromating vats is recommended.

Summary

Protective surface treatment of magnesium-base alloys, to D.T.D. 118 and D.T.D. 120A, by immersion or anodic treatment in mixed solutions of selenious acid and sodium dichromate have been investigated. The influence of time of immersion, temperature of the solution and the concentration ratio of selenious acid and dichromate have been studied.[8]

It has been shown that with D.T.D. 120A alloy selenium-dichromate immersion treatment produces coatings which are more resistant to salt-spray attack and more effective as bases for paint than either selenium coatings or chromate coatings produced by bath (iii) of D.T.D. 911.

The operational life of the solutions is exceptionally long, the coatings are free from odour and with the one alloy tested, the treatment has but little effect upon its fatigue endurance limit.

The composition of the coatings consists largely of selenium but some chromium, probably as sparingly-soluble chromate, is also present and may account for the marked difference in the properties of these coatings compared with those of selenium coatings.

A recommended bath consists of an aqueous solution of 7·5% (w/v) sodium dichromate plus 3% (w/v) of selenium dioxide used at its boiling point. Alloy to D.T.D. 120A is immersed therein for 30 minutes, but 5 minutes' immersion only is recommended for alloy to D.T.D. 118 followed by mechanical removal of the thin loosely adherent surface layer if the coating is to be used as a base for paint.

Acknowledgments

Acknowledgment is due to Mr. S. J. Lee for assistance in making many of the tests and to Messrs. I.C.I., Ltd., Paints Division, Slough, for carrying out the accelerated weathering tests on the painted panels. The author's thanks are also due to the directors of High Duty Alloys Ltd., for permission to publish this paper.

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2 Fournier, *Metaux*, 1934, **9**, 506; Cournot, J., and Halm, L. *Compt. rend.*, 1937, **204**, 1941; Sawamoto, H., *Suigokwai-Shi*, 1938, **9**, 459.
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4 Whitby, L., *J. Soc. Chem. Ind.*, 1931, **50**, 83T.
5 By courtesy of Messrs. I.C.I., Ltd., Paints Division, Slough.
6 This cycle consists of exposure of the panels to the following sequence:—
(*a*) Incubation at 65° ± 1° C. for 16 hours.
(*b*) Exposure for 8 hours to ultra-violet radiation (from a mercury discharge lamp) with half the panel immersed in water.
(*c*) Refrigeration at — 20° ± 1° C. for 16 hours.
(*d*) Exposure to salt spray at 60° ± 10° F. for 8 hours.
(*e*) Storage in a cabinet at 45° ± 1° C. and high relative humidity for 16 hours.
(*f*) Rest period under normal room conditions for 8 hours.
7 In this test a steel die is used to cut through the paint coating with a number of cuts at right angles to each other enclosing approximately 122 squares of paint each of 1mm. side. Adhesion is assessed by the number of such squares from which the paint is removed on brushing.
8 Patent protection for these treatments is covered by High Duty Alloys, Ltd., W. E. Prytherch and L. Whitby, Brit. Pat., 577,731, 1946.

The Influence of Calcium on the Creep Characteristics of Lead

By J. Neill Greenwood, D.Sc., M.Met.E.* and J. H. Cole, M.Sc.†

The addition of small amounts of calcium to lead results in a marked reduction in the creep rate, and although there are indications that ageing occurs after rolling, calcium lead still shows to advantage compared with pure and copper lead. The age-hardening which occurs during the 10 hours after quenching has apparently little effect on the long-term creep results. There are certain technical difficulties with calcium lead, but these need cause little or no trouble, provided they are anticipated and the conditions adapted accordingly.

IN previous articles[1, 2, 3] the authors have given results of long-time creep experiments on industrial leads and on alloys of silver and of copper with lead. In the present article, some corresponding results for calcium lead alloys are given. Some of these are supplementary to those of Greenwood and Orr[4], the remainder being new.

There are essentially three series of experiments :—

(*a*) Tests at ordinary temperature carried out at stresses of 500 and 350 lb./sq. in., respectively.

(*b*) Tests at 50° C. under a stress of 350 lb./sq. in.

(*c*) Tests associated with ageing characteristics :—

(*c*1) After rolling.

(*c*2) After quenching from 300° C.

Tests at Ordinary Temperatures—18° C.

The preparation of the rolled strip and the experimental details of the creep tests were exactly as described previously[1, 2, 3]. At each stress the alloy was tested in three conditions :—

(*a*) As rolled.

(*b*) After annealing 100° C. for 15 minutes.

(*c*) After annealing 125° C. for 24 hours.

The results obtained during six years are given in Tables I and II. The increased length of time compared with the previously published results[4] brought out no new features.

At the end of two years one group of test pieces which had been subjected to stress at 350 lb./sq. in. (Table II) was tested to destruction in a tensile test. This was to discover whether any embrittlement had occurred similar to that discovered in low magnesium lead alloys[5]. For the sake of completeness these tensile results are repeated here in Table III. The complete test occupied 7 minutes in each case.

TABLE I.—PERCENTAGE EXTENSION OF CALCIUM-LEAD ALLOYS
Stress, 500 lb./sq. in. Temperature, 18° C.

Ca Per Cent.	Duration (years) 1	2	3*	4*	5	6	Average rate/year
As rolled (stood one week) :							
nil	15·0	—	—	—	—	—	—
0·005	0·3	0·5	0·7	0·8	0·95	1·1	0·18
0·008	1·0	1·7	2·4	3·1	3·7	·44	0·73
0·055	0·07	0·095	0·12	0·15	0·18	0·20	0·03
0·105	0·045	0·05	0·055	0·06	0·065	0·07	0·01
Annealed 100° C./15 *minutes* :							
nil	Broke	—	—	—	—	—	—
0·005	1·4	1·8	—	—	—	—	—
0·008	3·5	4·7	—	—	—	—	—
0·055	0·05	0·07	—	—	—	—	—
0·105	0·035	0·045	—	—	—	—	—
Annealed 125° C./24 *hours* :							
nil	14·5	—	—	—	—	—	—
0·005	0·5	0·85	1·1	1·3	1·5	1·7	0·28
0·008	1·3	2·0	2·4	2·8	3·2	3·5	0·58
0·055	0·11	0·12	0·13	0·14	0·15	0·16	0·03
0·105	0·04	0·044	0·048	0·052	0·056	0·060	0·01

* By interpolation.

TABLE II.—PERCENTAGE EXTENSION OF CALCIUM-LEAD ALLOYS
Stress, 350 lb./sq. in. Temperature, 18° C.

Ca Per Cent.	Duration (years) 1	2	3*	4*	5	6	Average rate/year
As rolled (stood one week) :							
nil	2·5	4·2	5·3	6·8	9·5	11·6	1·9
0·005	0·14	0·20	0·25	0·29	0·34	0·38	0·06
0·008	0·50	0·85	1·15	1·45	1·75	2·10	0·35
0·055	0·04	0·05	0·065	0·07	0·075	0·08	0·01
0·105	0·04	0·05	0·055	0·06	0·07	0·08	0·01
Annealed 100° C./15 *minutes* :							
nil	2·3	3·7	5·0	6·2	6·9	7·3	1·2
0·005	0·22	0·33	—	—	—	—	0·17
0·008	1·09	2·45	—	—	—	—	0·72
0·055	0·02	0·04	—	—	—	—	0·02
0·105	0·05	0·06	—	—	—	—	0·03
Annealed 125° C./24 *hours* :							
nil	2·7	5·0	7·5	10·3	14·5	—	3·0
0·005	0·13	0·16	0·19	0·23	0·27	0·31	0·05
0·008	0·20	0·34	0·45	0·54	0·63	0·71	0·12
0·055	0·05	0·05	0·05	0·05	0·05	0·05	0·01
0·105	0·045	0·045	0·045	0·045	0·045	0·045	0·01

* By interpolation.

TABLE III.—TENSILE TESTS ON CALCIUM LEADS AFTER TWO YEARS UNDER 350 LB./SQ. IN. STRESS
Test pieces originally annealed 100° C. for 15 minutes
Temperature, 18° C. Time in testing, 7 minutes

Ca %	Tensile Strength lb./sq. in.	% Elongation 4 in.
nil*	1680	67
0·005	2040	31
0·008	2100	44
0·055	4850	17
0·105	6000	15

* This specimen had not been under stress previously.

The extraordinary effect of 0·05% calcium on the creep rate and strength of lead is here noted.

A further indication of the effect of calcium on the creep rate of lead was obtained from the results on test pieces which were tested at 50° C. (see next section) and then were allowed to stand under stress at ordinary temperature for nine years. The values are given in Table IV.

Tests at 50° C.

The material for these tests was rolled at the same time as that used in the above-mentioned experiments, but stood at 18° C. in the laboratory for two years before this series was started. The significance of this will be evident when the influence of ageing is considered in the next section.

* Research Professor of Metallurgy, Baillieu Laboratory, University of Melbourne.
† Formerly Research Scholar, School of Metallurgy, University of Melbourne, now Metallurgist, Defence Research and Industrial Laboratories, Maribyrnong.

TABLE IV.—ELONGATION OF CALCIUM LEADS AFTER STRESSING AT 50° C.
Stress, 350 lb./sq. in. Temperature, 14/25° C.

Ca %	% Extension in 9 years	Average Rate % Per Year
nil	Broke in 3½ years	—
0·005	0·34	0·04
0·008	0·17	0·02
0·055	0·11	0·01
0·105	0·08	0·01

These tests were carried out simultaneously with those reported in previous articles[2, 3] and the duration of stress was 280 days. For purposes of comparison, the curves have been extrapolated to 300 days. Simple extensometers were used to give a magnification of ten times, as from previous experiments it was anticipated that the creep rate would be low.

The results are given in Table V.

TABLE V.—PERCENTAGE EXTENSION OF CALCIUM-LEAD ALLOYS
Stress, 350 lb./sq. in. Temperature, 50° C.
Annealed 100° C. 15 minutes after standing two years after rolling

Ca %	Extension after 300 days		Ratio A/B
	50° C. (A)	18° C. (B)	
nil	6·2	2·0	3·1
0·005	0·23	0·20	1·1
0·008	0·16	1·0*	0·16*
0·055	0·16	0·04	4·0
0·105	0·016	0·05	0·3

* It is considered that the relatively high rate of creep at 18° C. was due to ageing changes taking place following cold-rolling.

It will be noted that the results on the 0·008% Ca lead which appeared abnormal in the tests at 18° C., fall in logical order in this series of tests. The significance of this will also be seen in the next section.

The Ageing of Calcium Leads

The work reported in the earlier sections of the article showed that cold work effects were retained to a marked degree by these alloys and there was therefore the possibility of ageing changes corresponding to a spontaneous anneal.

Also a study of the equilibrium diagram by Schumacher and Bouton[6] (given in Fig. 1) shows the possibility of retaining a super-saturated solution of calcium in lead by quenching and the corresponding possibility of age hardening effects by the precipitation of the intermetallic compound $CaPb_3$.

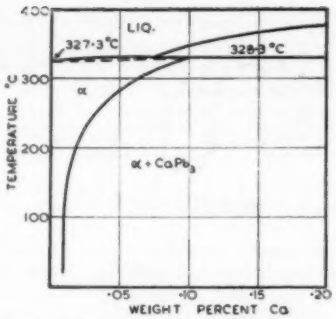

Fig. 1.—Phase diagram for calcium lead alloys up to 0.2% calcium (after Schumacher and Bouton).

It was thought that both these effects might have an influence on the creep characteristics. Consequently, two series of tests were started on an alloy containing 0·05% calcium:—

(*a*) At different times after rolling.

(*b*) At different times after quenching.

Influence of Time after Rolling

The average creep rate of the 0·05% calcium alloy used in the previous experiments was of the order of 10^{-6} strain per day under a stress of 500 lb./sq. in. over a period of six years. To increase this rate, the stress was raised to 700 lb./sq. in. for these new experiments. Otherwise the conditions of stressing were the same as before.

Creep tests were started at intervals of 1 day, 1 week, 1 month, and 6 months after rolling. The ingot was rolled the same day as cast, so that it is possible in this series that both types of ageing might occur.

Hardness tests were made on the strip for a period covering more than 300 days. The original hardness (tests made with a dead load machine using 5 mm. ball, 10 kgm. load applied for 30 secs.) was 7·7. After a week, this had fallen to 7·3 and this was followed by a gradual rise in hardness, a maximum of 8·1 being reached after 6 months. During this time a change was noted in the microstructure. Fig. 2 shows the structure at low magnification one day after rolling. The grains are elongated but recrystallisation had definitely started. After 6 months (Fig. 3), elongated grains were still visible but the recrystallisation had obviously progressed.

The creep characteristics are given in Table VI.

The characteristics are best shown by the curves in Fig. 4 from which it will be seen that the creep rate after standing 6 months in a stress-less state is appreciably greater than for those pieces which had stood shorter times. It is interesting to note, however, that there is no indication in the other three curves that any corresponding change had occurred in the specimens under stress. The broken line in Fig. 4 is a continuation of the creep rate established between 6 months and 12

Fig. 2.—Microstructure ×10 of 0.05% calcium lead one day after rolling.

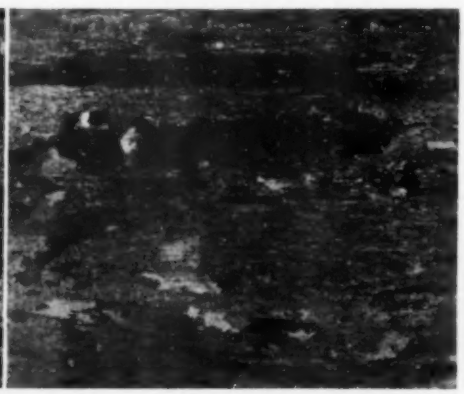

Fig. 3.—Microstructure ×10 of 0.05% calcium lead six months after rolling.

months under stress for the specimen which stood 6 months before putting under stress.

It will be recalled that in the previous section, attention was drawn to the anomalous behaviour of the 0·008% calcium alloy which immediately after rolling had a creep rate higher than that of the 0·005% calcium alloy. In the tests at 50° C. and the subsequent period of nine years at ordinary temperatures, it falls into line with a creep rate intermediate between those for 0·005% and 0·055%. This is thought to be due to spontaneous annealing which occurred during the two years between rolling and starting the test. It is well known that the creep rate rises considerably during the annealing of cold work material under stress. It is noted, however, that the 0·008% calcium alloy maintained a higher creep rate during the whole progress of the test, i.e., 5½ years and not only during the period when spontaneous annealing might be expected to be taking place, i.e., for the first two years.

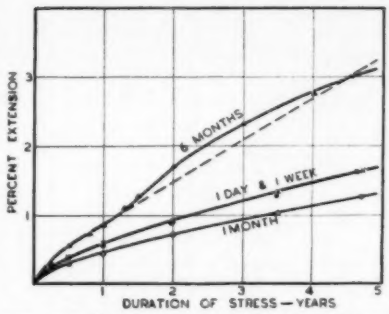

Fig. 4.—Creep curves of 0.05% calcium lead as rolled, showing influence of time after rolling before starting test. 700 lb./sq. in. stress.

Ageing after Quenching

Some preliminary experiments established the general characteristics of ageing after the alloy had been quenched from 300° C.

Specimens of 0·05% calcium lead alloy were annealed for 24 hours at 300/310° C. and water quenched. The alloy after this treatment consisted of a single phase and the grain size was 1–3 mm. diameter.

A series of such specimens was hung under various stresses to determine whether age-hardening was affected by stress. Hardness determinations were made immediately after quenching and at intervals—the loads being removed for as short a time as possible for this purpose. The results are given in Table VII.

The curve given in Fig. 5 is typical of all, showing that stresses up to 700 lb./sq. in. are substantially without effect on the age hardening. The hardness value reached a maximum after about 10 hours, fell slightly and then remained substantially constant over 200 days.

TABLE VI.—INFLUENCE OF TIME AFTER ROLLING ON PERCENTAGE EXTENSION OF 0·05% CALCIUM LEAD
Stress, 700 lb./sq. in. Temperature, 18/20° C.

Time from Rolling to applying stress	Initial ext.	Duration of stress (years)						Average % rate/year
		½	1	2	3	4	5	
1 day	C·919	0·4	0·6	0·9	1·2	1·5	1·7	0·34
1 week	0·027	0·4	0·55	0·9	1·2	1·5	1·7	0·34
1 month ..	0·023	0·3	0·45	0·7	0·9	1·1	1·3	0·26
6 months ..	0·008	0·5	0·85	1·7	2·3	2·7	3·0	0·60

Since ageing of this nature may also cause changes of dimension, an experiment was carried out to determine the order of length variation as this might affect the creep measurements in the early stages. A 4 in. length of the alloy, quenched after 24 hours at 300° C. to retain the α solid solution was placed in a silica tube and dimensional changes were transmitted to a dial gauge by means of a silica rod. Readings were taken at intervals over about 6 days. The results are shown in Fig. 6. It will be seen that the length increased to a maximum after 10 hours (corresponding with the hardness maximum). During the next 20 hours the length change was completely reversed and thereafter there was a slow expansion. The order of the dimensional changes was, however, too small to affect the creep readings.

Creep tests under a stress of 700 lb./sq. in. were started at times after quenching based on the above results.

The results are plotted in Fig. 7 from which it will be seen that except in minor details there is no substantial effect noticeable in 3 to 5 years. In fact, the major difference is traceable to the changes which occur in the rate of creep during the first few hours. After 1½ to 2 years all specimens reached the same minimum creep rate which had the very low value of $0{\cdot}7 \times 10^{-6}$ strain per day, under a stress of 700 lb./sq. in.

TABLE VII.—BRINELL HARDNESS OF 0·05% Ca ALLOY UNDER STRESS AFTER QUENCHING 300° C.
(5 mm./10 Kgm./30 secs.)

Time after quenching	Stress lb./sq. in.			
	nil	350	500	700
10 mins.	5·1	5·4	4·6	5·3
20 „	5·9	—	—	—
2 hours	6·5	6·4	6·2	5·5
4 „	7·6	7·7	7·4	—
6 „	8·7	8·4	7·8	8·5
8 „	8·6	8·7	7·7	7·8
10 „	9·3	8·7	8·7	9·0
12 „	8·4	8·4	8·2	8·6
14 „	8·4	8·6	8·0	8·3
20 „	8·3	8·3	8·0	8·3
2 days	8·3	8·3	7·9	8·7
4 „	8·6	8·4	8·0	8·6
18 „	8·6	9·7	8·4	8·7
100 „	9·0	8·8	9·0	8·5
200 „	9·2	8·7	9·0	8·7

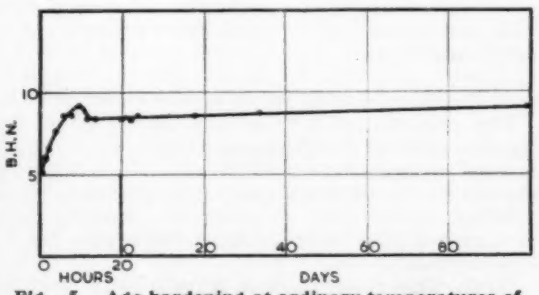

Fig. 5.—Age hardening at ordinary temperatures of 0.05% calcium lead after quenching from 305° C.

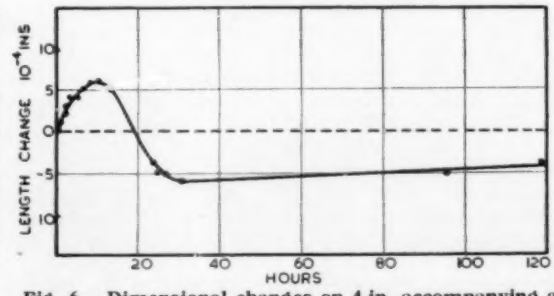

Fig. 6.—Dimensional changes on 4 in. accompanying age hardening of 0.05% calcium lead, quenched from 305° C.

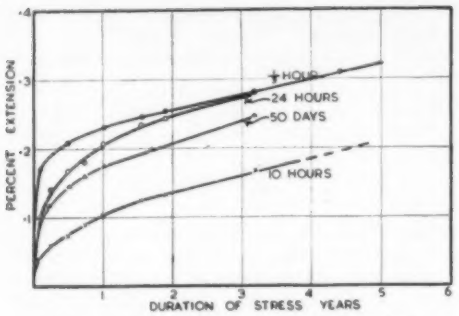

Fig. 7.—Influence of age hardening on creep characteristics of 0.05% calcium lead. Tests started various times after quenching. 700 lb. sq. in. stress.

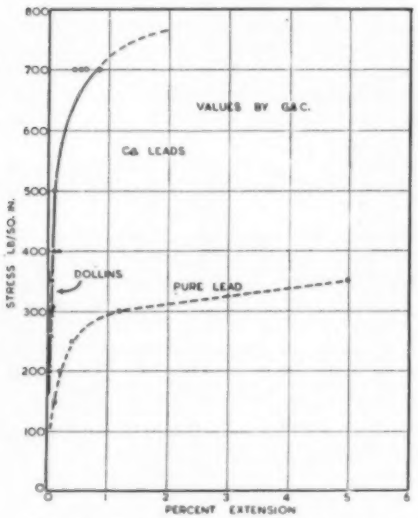

Fig. 8.—Creep yield curves per cent. extension in one year at ordinary temperatures for calcium leads. Composite curves including American results.

Consideration of Results

1. The main result of importance arising from these experiments is the confirmation of the marked reduction in creep rate brought about by the addition of very small percentages of calcium to lead. Table IV in particular, showing the results of observations over nine years, reveals that even 0·005% calcium changes the order of magnitude of the creep rate. Whereas the basis lead under a stress of 350 lb./sq. in. broke after 3½ years, the alloy with 0·005% calcium only stretched 0·34% in nine years.

2. This result is confirmed by the work of Dollins[7] using various calcium leads in which the calcium content was between 0·02% and 0·04%. The basis leads to which these additions were made were of various grades, several containing up to 0·05% copper and others containing appreciable percentages of arsenic, antimony and tin. In Fig. 8, some of these results have been combined with those here reported in the form of a creep yield curve. This indicates that with 0·05% calcium at ordinary temperatures a rate of creep of 1% per year can be expected with a stress of more than 700 lb./sq. in. The comparison curve for pure and copper leads taken from a previous article[3] shows this extraordinary effect.

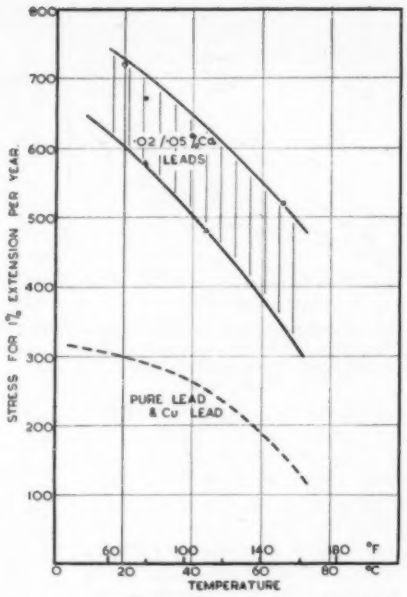

Fig. 9.—Estimated stress to give 1% extension per year at different temperatures for calcium leads. Composite results.

3. From the same work by Dollins an idea can be obtained of the effect of temperature on the creep yield stress of these alloys. Because of the wide variation in the composition of the basis leads, and the fact that no stresses greater than 400 lb./sq. in. were used, the results plotted in Fig. 9 can be taken as a guide only. Most of the points have been obtained by extrapolation, using other curves as a guide. The values thus obtained fall in a zone, but the advantage over pure and copper leads deformed at ordinary temperatures seems to be maintained up to 70° C. (160° F.). This is confirmed by the results given in Table V for a temperature of 50° C. (120° F.).

4. Although there are indications (Fig. 4) that ageing occurs after rolling, the results shown in Fig. 8 (in which the creep yield curve is drawn through the point showing greatest creep rate under the conditions) indicate that even so the calcium leads show a big advantage over pure and copper leads.

5. Quenching a 0·05% calcium lead after annealing at 300° C. to obtain all the calcium in solid solution gives an alloy with a still lower rate of creep—namely, about 0·2% extension in 4 years under a stress of 700 lb./sq. in. This should be compared with an extension of 1% in one year under a stress of 350 lb./sq. in. for the basis lead.

Although age hardening occurs during 10 hours after quenching this has little effect on the long-term creep results.

6. No intercrystalline embrittlement has been noted with the calcium leads comparable with that found for magnesium leads[5].

Technical Difficulties with Calcium Leads

The properties of calcium leads appear to be outstanding and this should naturally lead to a considerable increase in their use. It will be found as is frequently the case, that new technological difficulties arise. Some of these have been noted in the relatively small experience gained in producing the specimens used in this research.

In the first place, there is difficulty with the dross which forms during melting the alloy. The authors

found it convenient to introduce the calcium in the form of a mother alloy containing 1·8%. Calcium raises the melting point of lead very sharply, the mother alloy mentioned being completely molten only at 550° C. It is necessary to heat the lead to a higher temperature than usual before casting, though not of course to 550° C. The mother alloy will dissolve at a lower temperature. However, time must be allowed for complete solution and constant stirring is needed to avoid irregularities of composition. Because of the high temperature more dross is likely to form even if the surface is kept covered with charcoal. Also, calcium being a readily oxidisable element and giving rise to a highly refractory oxide, films of CaO are liable to form at any newly exposed surface. During casting, therefore, included films of CaO may be formed and become incorporated in the ingot. For this reason a higher casting temperature is desirable to allow these films to rise to the surface. Naturally, this is a vicious cycle, for the higher the temperature, the more readily will the calcium oxidise. Greater care needs to be exercised in holding back scum during pouring.

The next point is that as the alloy is appreciably stronger than pure lead (or copper lead) as shown in Table III, greater pressures will be needed in extruding and rolling unless these operations are carried out at temperatures higher than is usual. During rolling operations, the alloy hardens much more than normal leads, and unless precautions are taken, severe cracking of the edges may occur.

All these matters of technique need give little or no trouble so long as they are anticipated and conditions adapted. The enchancement of properties to be obtained appears to be well worth the trouble of adapting manufacturing conditions.

Although we have had no experience with " burning " calcium lead, one could readily anticipate difficulty due to the formation of a calcium oxide film during this operation. This, and possible difficulties during soldering would well repay some investigation. Possibly the use of a flux would mitigate any such film formation.

The improvement of resistance to creep (one of the worst features of lead as a structural material) by small additions of calcium should encourage further research on these lines. When an addition of 0·05% of an element can more than double the strength, it is obvious that something can be done to offset one of the great disadvantages of this material, namely, its high density. At the same time, a cautionary note should be sounded. The authors know of no work on the corrosion resistance of calcium leads and although they have no reason to suspect that this property will have deteriorated as compared with pure lead, the matter should be subjected to experimental observation.

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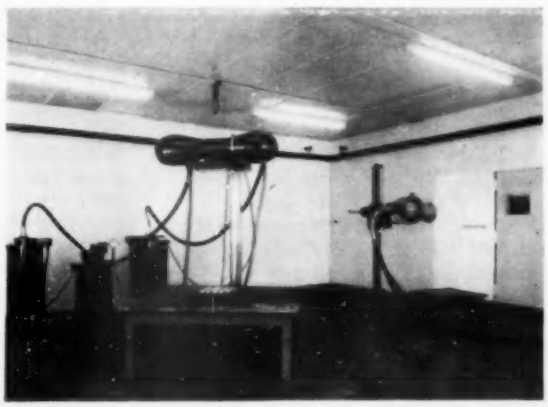
A New Laboratory for the Radiography of Cast Blades

Controlling Production by the Lost Wax Process

THE development of the gas turbine has brought in its train many problems of a metallurgical nature. Interest has naturally been focused on alloys for use at elevated temperatures and in this connection no little attention has been directed to the problem of their fabrication. Alloys which have good mechanical properties at high temperatures are usually difficult to forge. Many of the alloys suitable for high temperature use are also difficult to machine and one or two are completely unmachinable, except by grinding. In consequence attempts have been made to solve the problem by casting components close to size so as to minimise machining, or to obviate it altogether, apart from a final grinding operation. The most successful method to date has been the *cire-perdue*, or lost wax process, which has long been used by sculptors but has only recently been applied to engineering castings. The main application of the process has been in the production of stationary blades in a variety of alloys and Armstrong Siddeley Motors have recently set up a new radiographic laboratory to control the process in connection with their development work on gas turbines.

The laboratory comprises a suite of three rooms, the largest of which, measuring 30 ft. × 20 ft., houses the X-ray equipment. Adjoining are the dark-room and the control room, suitably protected from stray radiation by a ¾ in. layer of barium plaster on the inside of the equipment room walls and a further ¾ in. in the wall cavity. The doors are lined with ¼ in. lead and interlocking devices ensure that the set is shut off in the event of the door being accidently opened. Built into the wall between the control room and the set, is a standard viewing screen which may be used for screening work on light alloys.

The equipment room has, of necessity, no windows,



General view of the equipment room showing a batch of blade castings set up for radiographing. On the right may be seen the 150 kVp. set and the viewing screen.

General view of the dark-room. The viewing cabinet is seen on the left and the drying cupboard on the right whilst back centre is the film processing unit.

but the cream-painted walls and fluorescent lighting combine to give it a cheerful appearance. The instrument installed for the work on cast blades is a Siemens-Schuckert Type C1 set, rated at 220 kVp. and 15 mA.

The X-ray tube itself is of compact and robust construction and is designed for oil immersion and pressure oil cooling. Enclosed in an envelope of Pyrex glass, the target consists of a large tungsten disc vacuum cast into the copper anode block. The 12 ft. long high tension cables which are provided with detachable high tension unions for coupling to the generator and tube shield, enter the latter at right angles to the tube axis. By means of the rotatable centre section of the tube housing, the tube may be rotated through 180° (i.e., beam vertically downwards to vertically upwards), without movement of the cables. The ray-port is provided with a hand-operated remote-controlled four-leaf diaphragm. Support for the tube is provided by a robust and flexible stand, mounted on castors, which permits rotation of the tube about all axes. A press-button operated, motor-driven system is incorporated for vertical movement of the tube which may also be tracked backwards and forwards to facilitate horizontal focussing.

The high tension generator comprises a full Villard circuit housed in two oil-filled tanks, each tank being mounted on a castor base and containing a high potential transformer, a filament transformer for the rectifying valves, a high potential voltage doubling condenser, a high ohmic damping resistance, rectifying valves for operation at voltages up to 140 kVp. inverse, and various high potential and low tension insulators, bushings and glands. The generator, being designed on the Villard principle, delivers rectified pulsating voltage to the X-ray tube.

Cooling oil, at a pressure of about 55 lb./sq. in. is supplied to the X-ray tube anode by an electric pump capable of maintaining a smooth flow of oil without pulsation. The reservoir contains sufficient oil to enable the tube to run intermittently, in emergency, without secondary water cooling, and a temperature indicator is incorporated for this purpose. A master switch shuts off the equipment if the oil pressure falls below a predetermined safe working pressure.

The control desk, which is located outside the room housing the set, is provided with a combined sloping instrument panel and a horizontal control panel. Housed in the desk are the main fuses, circuit control contactors, safety relays, motor-operated tube voltage regulators and motor-operated tube current regulators. The panel supports instruments for indicating tube voltage and current, a synchronous auto-timer (with a range from five seconds to five minutes), eight press buttons for: (*a*) Switching the set on and off; (*b*) automatic increase and decrease of tube voltage to pre-determined values; (*c*) similar automatic current control; and (*d*) exposure time control. Automatic protection is provided against excessive tube current, application of excessive voltage to the tube when cold and application of voltage to the tube and rectifying valves before the filaments thereof have reached a stable temperature. It will be seen that the entire X-ray circuit is controlled by eight press buttons only.

The well equipped dark-room is fitted with an Ilford X-ray film processing unit comprising developing, fixing and washing tanks. To assist in standardising the development procedure the developing tank is fitted with automatic temperature control. A Kodak drying cupboard enables films to be dried, ready for examination, in a matter of twenty minutes. For examination of the radiographs, a Kodak viewing cabinet is available.

Whilst the laboratory forms a link in the chain of inspection devised to ensure that only sound blades are released, it also performs an equally important function in helping to develop the correct casting technique for each particular type of blade. Radiography provides a ready means of determining whether the casting temperature and feeding arrangements have been such as to ensure the absence of such defects as blowholes, shrinkage porosity and piping. Lest it be imagined that the work, from the radiographic technique viewpoint, is largely of a routine nature, it should be realised that the change in section from the centre to the edge of the blades, combined with the widely varying amounts of relatively radiographically dense alloying elements used, calls for a considerable degree of skill in producing satisfactory radiographs.

Prior to the setting up of the new laboratory, a certain amount of X-ray work was carried out elsewhere in the factory on light alloy castings and on welding development. The whole has now been centralised and the equipment room also houses the Phillips 150 kVp. Macro set used for this purpose.

Light Alloy Engineering Merger

HEAD, WRIGHTSON & CO., LTD. the engineers of Thornaby-on-Tees have acquired the businesses of: F. J. & L. Dean, Slough, Bucks., Consultants in aluminium fabrication, Aldean Designs Ltd., Slough, Bucks., Designers of aluminium structures, and D. J. Hawkins & Sons, Ltd., Stoke Row, Henley-on-Thames, Oxon., Fabricators in aluminium.

These businesses are being amalgamated with their subsidiary Head Wrightson Light Alloy Structures, Ltd., designers and builders of the first aluminium alloy bascule bridge in the world erected at Sunderland. The Head Wrightson Light Alloy Structure company will in future be known as Head Wrightson Aldean Ltd. with headquarters at 61, Windsor Road, Slough, Bucks.

The Company also announce that in addition to their present contracts, they have booked substantial orders for aluminium structures for the Channel Islands.

Blackheart Malleable Cast Iron

Its Production and Properties

At one time the malleable cast iron produced in this country was almost exclusively made by the whiteheart process; during the last few decades, however, developments in melting plant, the introduction of control facilities, and improved raw materials, have greatly increased the field for blackheart malleable castings, in the production of which great progress has been made. In this article the characteristics of blackheart malleable iron are discussed and methods employed in the manufacture, of castings are described with reference to a modern British plant.

IN the year 1820, Seth Boyden set up an iron foundry at Newark, New Jersey. Knowing of European or whiteheart malleable cast iron, he foresaw a potential market for the material in the rapidly expanding American industries and, in 1826, he started a series of experiments by which to acquire the technique of making malleable castings. From the diary of his investigations, it is clear that he was basing his work on that of Réaumur and had no thought but to produce whiteheart malleable iron. Constantly, in referring to his early trials, Boyden derogatorily described the fractures of his specimens as "black" or "grey", and of his eleventh experiment he wrote, "... the iron was tough when broken, but rather too dark in colour". In such a manner was blackheart or American malleable first produced, for the excellent mechanical properties exhibited by this "dark-fractured" material made further attempts to produce whiteheart malleable unnecessary.

At first used for saddlery, carriage and wagon parts and agricultural implements, blackheart malleable found increasing fields of usefulness as a result of the development of the railways and later of the automobile industry. Up to the last thirty years, the malleable iron produced in this country — with the exception of the small output of the few blackheart pioneers — was whiteheart, but the introduction of modern methods of melting, and closer control of the various processes and of the raw materials used, has led to an ever increasing use of blackheart malleable.

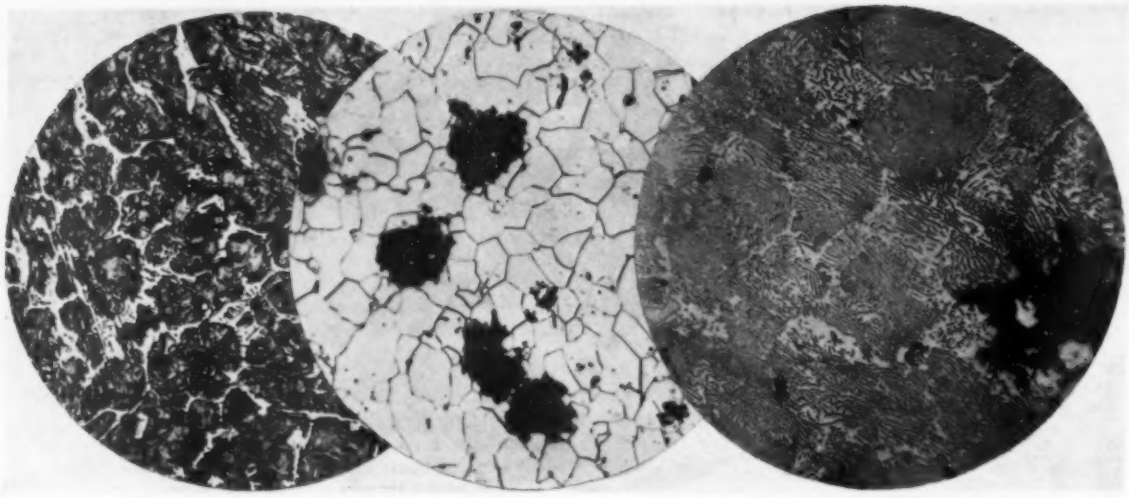
Blackheart or Whiteheart

Depending on its chemical analysis and rate of cooling from the molten state, the structure of cast iron may consist of graphite, ferrite and pearlite in the grey irons, cementite (iron carbide) and pearlite in the white irons, or a mixture of cementite, graphite and pearlite in the mottled irons which are partly grey and partly white in fracture. The graphite in normal cast iron, because of its flake form, exercises a considerable weakening effect and lowers the ductility and shock-resistance. White iron on the other hand, is extremely hard and brittle, and is, therefore, unsuitable for many purposes. In malleable iron castings, advantage is taken of the excellent founding properties of cast iron, whilst the mechanical properties are enhanced by heat treatment operations which result in important structural changes. Both the blackheart and whiteheart processes start with a white iron casting; in the former, graphitization results in a structure in which rosettes or nodules of temper-carbon are distributed throughout a ferrite matrix, whilst in the latter, the white iron structure is changed to one which ideally consists of ferrite only. The entirely ferritic structure is usually only achieved in castings of very thin section and it is more usual to find a middle zone containing pearlite in more substantial thicknesses of metal.

Réaumur, in developing the European process for the production of malleable iron, in the early part of the 18th century, worked on the principle that, if wrought iron could be made hard and brittle by carburising, cast iron should be made soft and ductile by carbon extraction. Réaumur's process consisted in heating the castings to red heat, in contact with powdered ore, for several days, and this forms the basis of whiteheart malleable production to-day. The reason Boyden did not succeed in producing whiteheart malleable lay in the composition of the iron he used, the silicon content being much higher than in Réaumur's iron. It is now well-known that silicon increases the tendency for graphitization to occur, both on solidification and on annealing, so that when Boyden heated his high silicon white iron castings, temper-carbon was deposited in the form of rosettes, and the fracture had a dark appearance. For a long time it was not realised that the effect was entirely due to holding the castings at a high temperature, and castings continued to be packed in ore, with the idea that the ore performed an important function in the process.

In both processes, it is essential that the iron, as cast, shall be completely white—i.e., entirely free from graphite flakes, which would persist throughout the heat-treatment operations and impair the mechanical properties of the finished product. The analytical requirements for blackheart malleable are, therefore, more stringent than those for whiteheart, because composition has an important bearing on the graphitization process. Accordingly, cupola melting is not the most reliable method of producing metal for the highest quality blackheart castings, the most satisfactory results being obtained from air-, open-hearth- and rotary furnaces.

It has been stated that the structure of whiteheart malleable consists of ferrite and pearlite grains; the ideal of complete decarburisation is seldom attained in practice, except in very thin sections, owing to the process being essentially one of decarburisation at the surface and carbon diffusion to the surface. At the same time, some graphitization may occur as in the blackheart process. When decarburisation has proceeded so far that there is no cementite left, the austenite tends to dissolve the precipitated graphite slowly. Carbon diffusion then becomes so slow that there is a risk of oxidation at the surface. Except in castings of thin



White cast iron. × **120**

Blackheart malleable cast iron. × **120**

Pearlitic malleable cast iron. × **250**

TABLE I.—MINIMUM MECHANICAL PROPERTIES OF BLACKHEART MALLEABLE IRON CASTINGS.

Grade	Sectional thickness represented	Dia. of bar — in.	U.T.S. Tons/sq.in.	Elongation % on 2 in.	Bend test. Degrees round 2 in. dia. mandrel.	Yield point.† Tons/sq.in.
*1.. ..	All sizes	0·564	18	6	30	10
2.. ..	All sizes	0·564	20	10	90	11
3.. ..	All sizes	0·564	22	14	135	12

* Grade I is included mainly to cover metal generally produced in a cupola furnace, intended for application where pressure tightness is more important than a high degree of strength or ductility. Grade I material may not be supplied against orders quoting B.S. 310 : 1947 unless specifically stated on the order.

† Optional.

TABLE II.—MINIMUM MECHANICAL PROPERTIES OF WHITEHEART MALLEABLE IRON CASTINGS.

Grade	Sectional thickness represented in.	Diam. of bar in.	U.T.S. Tons/sq. in.	Elongation	Bend test			Yield Yield point† Tons/sq. in.
					Bar size in.	Angle of bend degrees	Mandrel diam. in.	
1	Over $\frac{1}{2}$	0·564	22	4% on 2·0 in.	8 × 1 × 0·375	45	2·0	12
	$\frac{1}{8}$ to $\frac{1}{2}$	0·357	20	6% on 1·25 in.	7 × 1 × 0·25	45	1·75	11
	Under $\frac{1}{8}$	0·252	20	6% on 1·0 in.	6 × 1 × 0·15	45	1·25	11
2	Over $\frac{1}{2}$	0·564	24	8% on 2·0 in.	8 × 1 × 0·375	90	2·0	13
	$\frac{1}{8}$ to $\frac{1}{2}$	0·357	22	10% on 1·25 in.	7 × 1 × 0·25	90	1·75	12
	Under $\frac{1}{8}$	0·252	22	12% on 1·0 in.	6 × 1 × 0·15	90	1·25	12

† Optional.

section, there is usually some temper-carbon and pearlite in the centre and it is impossible to malleabilise large sections completely by the whiteheart process, a hard and somewhat brittle core being inevitable. On the question of size, blackheart has a decided advantage. There is, of course, a practical limit to the size of section with blackheart castings, due to the risk of precipitation of primary graphite. Heavy sections do not present the same difficulties as they did in the early days, the risk of primary graphite being considerably reduced by improved foundry technique and better metallurgical control.

The mechanical properties attainable on test bars of both types of malleable, as set out in B.S. 309 : 1947 and B.S. 310 : 1947 are given in Tables I and II. It will be seen that the yield point of the whiteheart material is slightly higher, but the ductility is less than that of blackheart. Both types are much stronger and more ductile than ordinary cast iron, and although not so wear-resistant as the high-duty cast irons, they are more ductile and shock-resistant. For many purposes, particularly in the small casting field, malleable cast iron can be used to replace steel and the lower melting-point enables more intricate shapes to be cast.

Blackheart malleable is more easily machined than steel, and whilst both types of malleable have reasonably good machining properties, blackheart is the better of the two, due to the presence of the graphite rosettes which act as a lubricant.

Neither type, except the completely ferritic thin-sectioned whiteheart, is suitable for ordinary case hardening due to the brittleness of the core after hardening.

Graphitization of Blackheart Malleable.

The production of malleable iron calls for strict control of the composition of the metal from which the castings are poured, in order to ensure that no primary graphite separates on solidification and that, on annealing, temper-carbon will be deposited as rosettes. A typical "as cast" analysis would be :—

Total Carbon %	Silicon %	Manganese %	Sulphur %	Phosphorus %
2·40–2·70	0·70–1·10	0·25–0·40	0·10 max.	0·10 max.

With too low a carbon figure, difficulty may be experienced in running light castings, unless offset by increased temperature. On the other hand, too high a carbon content will result in some weakening of the annealed castings, because of the excessive amount of temper-carbon produced.

As it is the combined effect of carbon and silicon which governs the graphitization, the silicon content is varied according to the carbon content. Excess silicon may result in the formation of primary graphite, whereas too low a silicon retards graphitization. It is good

practice to keep the carbon at a practical minimum and balance with an increase in silicon.

Sulphur, if controlled, exercises a stabilising influence on the iron carbide and retards graphitization, whilst manganese has a similar though less marked tendency. It is usual to have a slight excess of manganese above that required to ensure that all the sulphur is present in the form of manganese sulphide.

Having obtained castings of the desired composition, free from primary graphite, the next important operation is that of annealing. This consists of heating slowly to a temperature of 870°–920° C., maintaining for a predetermined period, depending on the temperature employed, followed by controlled cooling.

A general view of the moulding bays.

On reaching the A_1 point, on heating, the pearlite of the white iron changes to austenite and, as the temperature is increased above the Ac_1 point an increasing amount of cementite is taken into solution in the austenite until saturation is reached at the temperature of soaking. During the soaking stage, the austenite deposits nuclei of temper-carbon and thereby reduces the concentration of carbon in the austenite. More cementite is then dissolved until saturation is again reached. The deposition of temper carbon and the solution of cementite proceed simultaneously until all the cementite is dissolved. This part of the process is known as first stage graphitization and is completed after soaking at temperature for the required time. The structure then consists of temper-carbon in a matrix of austenite saturated with carbon. As the temperature falls, solubility of carbon in austenite decreases, and on slow cooling, more carbon is deposited from the austenite until the critical temperature is reached. This is known as second stage graphitization and in this way, with a very slow cooling rate (certainly not greater than 7° C. per hour) through, and down to 20° C. below, the critical range, complete graphitization can be achieved. Further cooling may take place rapidly without alteration of the structure, which in a perfectly annealed casting, consists of a dispersion of rosettes of temper-carbon in a ferrite matrix. If the above procedure has not been properly carried out, some cementite or pearlite may be present.

Blackheart Malleable Iron Plant and Practice

We were recently privileged to visit the works of Messrs. Hale and Hale (Tipton), Ltd., one of the largest producers of blackheart malleable iron castings in the country, and we are indebted to the Directors and Staff of the Company for permission to describe their plant and practice, by way of illustrating the production of blackheart malleable, and for the photographs used in this article.

A section of the core shop.

The first foundry was opened at Walsall in 1909 by the Brothers W. E. and T. L. Hale, and was housed in a small stable. The business began to develop during the first world war and by 1918 it was necessary to move to more commodious premises. In 1919, the business was transferred to its present site at Tipton, which had ample room for development, and the foundries now occupy an area of more than 16 acres. In 1936, the company was re-formed as Messrs. Hale and Hale (Tipton) Ltd., under the chairmanship of Mr. W. E. Hale. Over the past 30 years, the company's annual output has risen to over 9,000 tons. Practically the entire output consists of castings to Grade III, the highest quality, of the British Standard 310 : 1947. In addition, a pearlitic material is being developed and is known as "Permalite." This is now being

Part of the melting shop. On the left of the photograph may be seen the burner end of one of the pulverised-fuel-fired open-hearth furnaces.

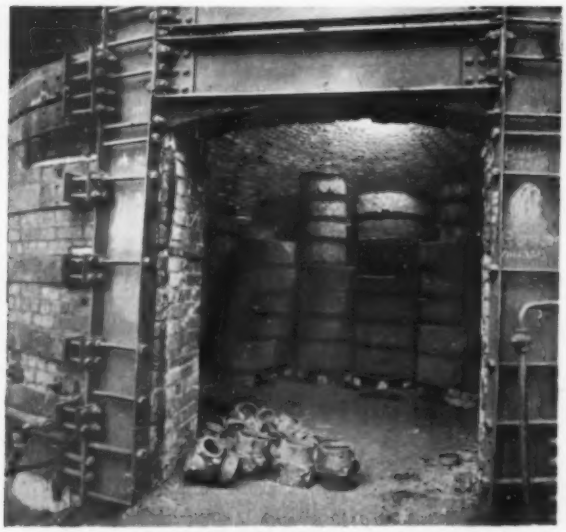
used for an increasing number of purposes and possesses the following mechanical properties :—

Ultimate Tensile Strength	30–35 tons/sq. in.
Yield Point	19–21 "
Elongation	6–8%
Bend	90°
Brinell Hardness	160–175

Patterns and Moulds

Careful consideration is given to the question of pattern equipment, whether for single castings or for quantity production. For small quantities, loose wood patterns are used, whilst for large quantity production the patterns generally used are of the plate type with brass or aluminium patterns on cast iron or aluminium plates. The well-equipped pattern shops are fitted with modern machinery capable of making all the master and production pattern equipment required in the foundries.

Moulding for malleable castings presents no unusual features. With the greater shrinkage, more feeders and risers are necessary than with grey iron and the higher melting point calls for a more refractory sand. In short, the moulding practice is more akin to that for steel than for grey iron. The sand mixture used is Red Staffordshire sand and old foundry sand, with a proportion of coal dust in the facing sand. For cores, silica sand is bonded with linseed base oils and drying is effected in coke-fired continuous stoves and a battery of thermostatically controlled gas-fired batch stoves, A small section of the foundry is devoted to the production of test castings. Before a run of castings is started, test castings are made and subjected to a searching examination to ensure that first-class castings are produced. It is these tests which govern the planning of the patterns and the feeding methods to be employed.



A " Beehive " type annealing furnace being charged with castings for annealing.

Tapping an open-hearth furnace.

The works laboratory is equipped with efficient sand testing equipment and sand control is effected by regular routine tests for permeability, moisture, green strength and, when required, carbonaceous matter ; fineness is also periodically checked.

A few large castings are hand-moulded, but the majority of the castings are moulded on machines in which the ramming is done mainly by hand, but the pattern is withdrawn mechanically. For certain types of castings, hydraulic and electrically-powered squeeze machines are in operation.

Melting and Casting

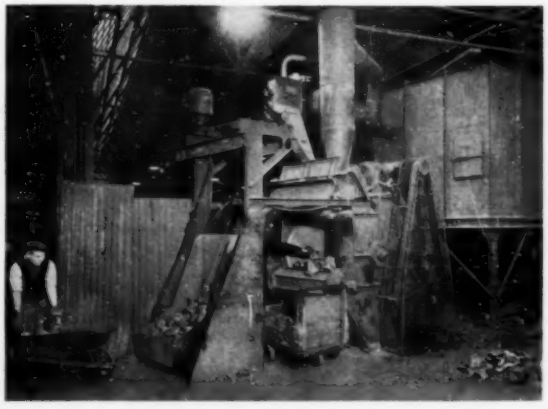
The melting installation comprises a battery of 20/30 ton pulverised-coal-fired open-hearth furnaces, fuel being supplied from a central pulveriser house.

Foundry scrap and hematite pig iron form the major part of the charge, small amounts of steel scrap being

added for the purpose of adjustment. The pig iron is stocked according to analysis which facilitates calculation of the charge to give the required metal analysis, allowing for the melting losses resulting from the oxidation of silicon, carbon and manganese.

From the chemical analysis of the melting sample, the additions necessary for analysis adjustment can be calculated and made accordingly. When the additions have had time to become incorporated in the bath a tapping sample is taken, and further slight additions are made if necessary. Tapping usually begins about an hour after the melting sample is taken and further samples for analysis are taken as considered necessary. "Rabbling" of the molten metal is an essential part of the process, as there is a tendency to surface oxidation. Charging of the furnaces is so arranged as to deliver metal to the foundries continuously.

General view of the chemical laboratory.



Shot-blasting equipment.

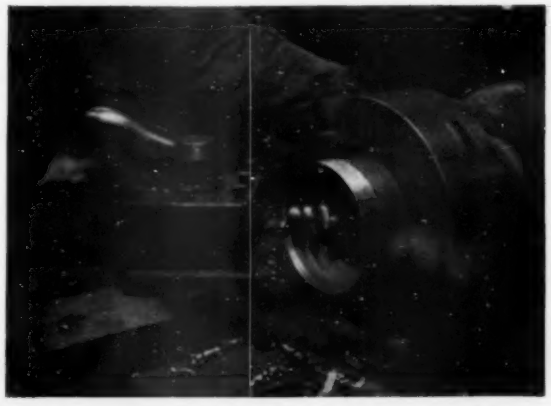
When poured, the castings are allowed to cool in the moulds and, after stripping, the runners and risers are broken off and the castings conveyed to the hard warehouse for cleaning, rough dressing and inspection. This entails the removal of some 80–100 tons of castings, runners and risers, to hard warehouse and stockyard, and this operation is completed in less than two hours each morning. After inspection, the castings are shipped to the annealing furnaces.

Annealing

The next stage is the all-important one of annealing. This involves heating slowly to the annealing temperature, soaking for a few days, followed by slow cooling, at least down to 690° C. The annealing plant consists of a number of gas-fired beehive furnaces, ranging from 18–50 tons capacity.

Unlike whiteheart production, in which the packing medium plays an important role in the malleabilising process, blackheart castings are packed in a chemically inert substance to minimise oxidation and distortion. The castings are packed in "cans" made of low grade white cast iron. These may be round or square and are usually open top and bottom; the wall thickness is about 2 in. Whilst round cans do not permit such close packing as square ones, they allow the hot gases to permeate the charge more easily and result in more uniform heating. The cans are stacked one upon the other as may be seen in the illustration, the bottom can being supported from the furnace floor to allow the hot gases to flow beneath it. As each can is filled, a further can is placed on top and the joint luted. When the furnace is filled the "wicket" opening is bricked up and the furnace charge heated slowly to the annealing temperature.

Control of the annealing process is obviously of primary importance. The gas burners, situated near the bottom of the walls, are divided into a number of sections, each controlled by a valve, and the temperatures of the various furnaces are recorded on two multi-



Machining blackheart malleable cast iron.

An assortment of blackheart malleable castings.

point recording instruments. In addition, regular optical pyrometer readings are taken. Standard test bars are annealed along with the castings.

From packing to unpacking takes 9–14 days, depending on the size of the annealing furnace. The furnaces cool naturally to 580° C. and then the "wicket" is broken down.

Fettling and Inspection

After annealing, the castings are ground, fettled, set in dies, if necessary, and shot-blasted, prior to final inspection. Castings which have been distorted may be corrected at 600°–650° C., but most distortion correction can be effected cold.

Control and Testing

From the foregoing, it will be appreciated that strict control is necessary at all stages if the highest quality blackheart malleable castings are to be produced. This is effectively ensured by the laboratory and inspection staff who exercise control from the entry of the raw material into the works to the dispatch of the finished castings.

The incoming pig iron is checked analytically and stacked according to analysis; the scrap charge is of known analysis; samples are taken on melting and at the commencement, middle and end of the tap and additions are ordered in line with the results of the chemical analyses. In this way the composition of the metal is controlled, and, in addition, a member of the laboratory staff checks the metal temperature during tapping, which enables uniformity of casting temperature to be maintained. Along with each tapping sample, British Standard test bars are cast for tensile and bend testing, the bars being annealed along with the castings.

The laboratory is well equipped for chemical analysis, sand testing, metallography and mechanical testing. The equipment includes a Vickers projection microscope and a 20-ton Avery hydraulic testing machine of modern design. Experimental heat treatment is also carried out in the laboratory.

The Uses of Blackheart Malleable

Some 200 tons of finished castings are produced weekly in weights ranging from a few ounces to 1½ cwt. each. With strict metallurgical control, blackheart malleable castings can now be produced with greater wall thickness than was at one time thought possible.

The largest users of blackheart malleable are in the automobile industry in which brake shoes, exhaust manifolds, spring brackets, back axle housings, differential parts, pedals, body fittings, etc., are produced in large quantities. Next comes the agricultural engineering industry, with the use of malleable for parts of ploughs, reapers and binders, harrows, planters, diggers, etc. In the heavy electrical industry blackheart malleable is used for mining switch gear, power station equipment, railway electrification and overhead power transmission. The heavier type of tube fitting as used in mining and heavy engineering, machine and hand tool castings, jack castings, conveyor belt parts, colliery release wedges and screw-type pit props are among the increasing number of uses to which blackheart malleable cast iron is being applied.

In general, it can be said that malleable cast iron is used where the higher mechanical properties of mild steel are not necessary, but where a strong, ductile, free-machining material of good finish is required. The reason for the increasing demand for blackheart malleable iron castings can be readily appreciated in view of the continual efforts of the leaders in the trade to improve the quality of their products. The range of usefulness of blackheart malleable has extended considerably since the war years during which period necessity proved the great value of the material to industry.

"B. O. C. Prize for Welding Research"

No award of the British Oxygen Company's £100 Prize for Welding Research has been made for 1948/49, but it is intended to offer the prize again this year, when it is hoped that a worthy paper will be forthcoming.

Candidates are required to submit an original unpublished paper, not exceeding 5,000 words, on a research into welding or its application, carried out in Great Britain or Northern Ireland. The competition is limited to candidates whose age does not exceed 35 years on January 1st, 1949, and evidence is required that the candidate has been mainly responsible for the work.

Independent Assessors, appointed by the Council of the British Welding Research Association, will have the right to make any enquiries necessary concerning the research that is the subject of the candidate's paper.

Papers should be submitted, on or before September 30th, 1949, to the Secretary, British Welding Research Association, 29, Park Cresent, London W.1, from whom fuller particulars may be obtained.

Brayshaw Furnaces and Tools, Ltd.

BRAYSHAW FURNACES AND TOOLS, LTD. have now completed arrangements for the manufacture and sale, under exclusive licence, of electric furnaces to the standard designs of the American Electric Furnace Co. of Boston, Mass., U.S.A. These electric furnaces will supplement the existing range of gas, oil and solid fuel furnace designs in which the Company has specialised for many years. Several models of the electric furnaces were exhibited at the Machine Tool and Engineering Exhibition held at Olympia last year.

THOSE seeking some information on the use of aluminium alloys in the manufacture of components for the electrical and wireless industry should obtain a copy of a recent publication on the subject by High Duty Alloys Ltd., Slough, Bucks. The illustrations indicate the wide range of applications that are being satisfactorily filled by the use of light alloys.

Dynamic Torsion of Metals and Alloys Used in Aircraft Construction

Their Elastic Limit and Micro-plastic Deformation Under Reversed Torsional Energy Loads—Part II

By Georges Welter

Professor of Applied Mechanics, Ecole Polytechnique, Montreal

In modern machinery practically all elements work under short-time repeated loading, and little data is available about the mechanical properties of structural materials investigated under these conditions. The present research has been carried out to investigate the maximum possible impact loads causing no permanent micro-deformation of the test specimen under plus and minus torsion loads.

In Table I are given some characteristics of the different alloys tested as: Aluminium light alloy 24ST. Magnesium ultra light alloy AM 57S, mild steel, Ni-Cr steel and Monel metal.

Test Results

The readings of the results of testing these materials under increasing static and dynamic loads have been recorded step by step in special tables. In each of these tables the static load was recorded, the telescopes' readings of the two torsiometers were checked under load as well as at zero load, and the elastic and micro-plastic deformations as well as the energy absorbed by the specimens were calculated.

However, to obtain a certain stability of the micro-deformations during the dynamic tests, the same impact load for all tests was applied five times before the telescope reading, indicating the permanent deformation, was recorded. Furthermore, the influence of the speed of the applied load on the different materials was studied by using a constant weight and an increasing dropping height. The energy absorbed was compared with results of tests carried out under increasing energy by using increasing weights falling from the same height. Several characteristic diagrams, representing the energy absorbed as a function of the permanent micro-deformation of the materials, have been recorded. For each of the specimens, after having attained a permanent deformation of a certain angle, the dynamic loads were reversed and the deformations under opposite loading senses recorded. In the diagrams of this kind, the curve, showing the first loading cycle of the virgin material, is labelled as No. 1; the second cycle of loading in the reversed sense gives a curve of permanent deformation which, due to locked up or residual stresses, is generally much lower than the first one (known as effect of Bauschinger). This curve is shown in the diagram as No. 2 (compare for instance, Fig. 12, A-B).

Furthermore, the influence of the loading speed on the elastic limit under permanent deformation of 0·004%, 0·01% and 0·02% or 0·05% has been recorded for duralumin and Monel metal (Fig. 13 and 34). On the other hand, the effect of Bauschinger, which seems to play a quite important role with the different structural materials under torsional loads, has been recorded for 0·004%, 0·01% and 0·02% or 0·05% and 0·1% of permanent deformation for duralumin and Monel metal (Fig. 14 and 35). For magnesium alloy 57S, mild steel, and nickel-chrome steel, this effect was recorded only for a permanent deformation of 0·01% (Figs. 19, 24, and 29). For the purpose of comparing the results recording the permanent deformation under reversed loading condition, a diagram, showing the different behaviour of the materials tested, is also added (Fig. 36).

Altogether, for this investigation, about 30 tables with static test results, each one with an average of 140–150 records, and about 60 tables with dynamic test results each one with an average of about 90–100 records, have been made, representing altogether over 10,000 individual readings of test results which are condensed in Figs. 10–36.

(a) Duralumin 24ST

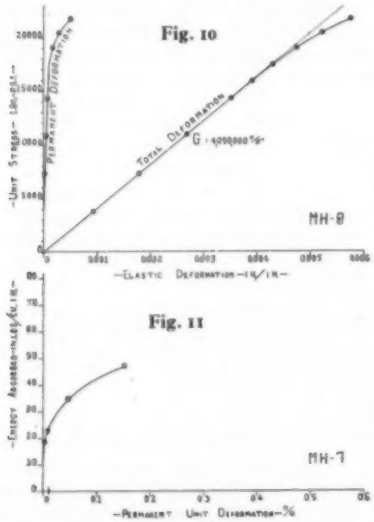
These results are shown in Figs. 10–14, of which the two first ones represent static torsion test results. As may be seen from the first figure, this alloy has a static elastic limit in torsion at 0·0001″/″ permanent deformation of about 17,500 lb./sq. in.; its torsion modulus has been found to be G = 4,090,000 lb./sq. in. (Fig. 10). The

TABLE I.

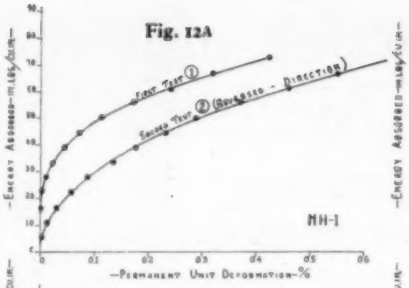
Material	Temper	Nominal Composition %	Typical mechanical properties: Yield strength lb./sq. in.	Typical mechanical properties: Ultimate tensile strength lb./sq. in.	Typical mechanical properties: Elongation % in 2 in.	Hardness Brinell 500 Kg. load 10 mm. ball
Aluminium alloy	24ST	Cu 4·5, Mn 0·6, Mg 1·5, Al Bal.	45,000	68,000	22	105
Magnesium alloy	AM 57S	Al 5·8–7·2, Zn 0·4–1·5, Mn 0·15, Si 0·3, Cu 0·05, Mg Bal	30,000–32,000	44,000	14–15	55
Mild steel	SAE 1020	C 0·22, Mn 0·48, P 0·018, S 0·03	30,000–35,000	60,000–65,000	25	125
Ni-Cr Steel..	Annealed	C 0·4, Mn 0·75, P 0·03, S 0·03, Ni 1·25, Cr 0·6, Mo 0·15, Si 0·2 ..	73,800	104,200	23·5	217
Monel metal K..	As drawn	C 0·14, Mn 0·75, Ni 64·25, Cu 29·72, Al 2·78, Si 0·31, Fe 1·44, S 0·005, Ti 0·58, Cr 0·02	109,000	122,100	25	Rockwell hardness 20

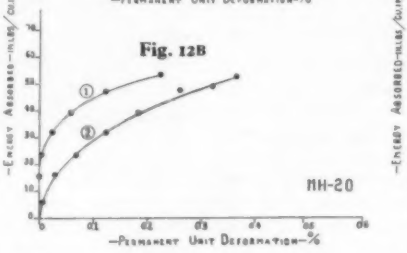
energy absorbed by duralumin during the static test as a function of its permanent deformation is represented in Fig. 11.

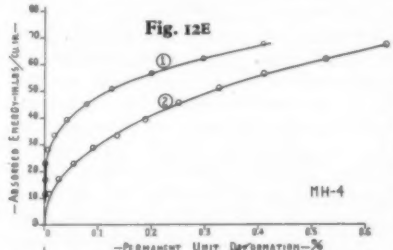
These alloys, under dynamic torsion, up to a certain amount of permanent deformation (0·42%), followed by a torsion in the opposite sense up to 0·7% permanent deformation, show results as given in Fig. 12A. The load of the hammer for these diagrams was 2 lb., and the dropping height was gradually increased in 13 steps of 1 in. up to about 72 in.-lb./cu. in. (curve No. 1). By a second cycle of loading in the opposite sense it is found that, in order to produce permanent deformation, the energy absorbed per cu. in. is surprisingly low; only a few in.-lb./cu. in. being necessary to produce a permanent deformation of about 0·001%. Under a 20 in.-lb./cu. in. load (curve No. 2), a point,

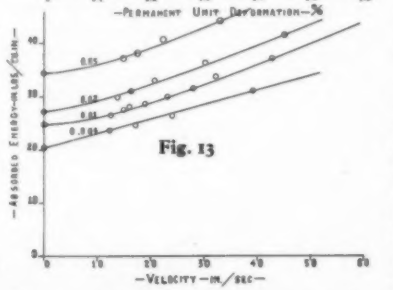


where the permanent deformation of virgin material is just starting, curve No. 1, a deformation of 0·05% has been measured, showing the weakness of the specimen against permanent deformation, a deformation due to residual stresses induced by the first cycle of loading. The sensitivity of this material against reversed stresses, acting on slightly preliminary overstressed material (0·42%) is visible by its total permanent deformation at the maximum applied energy load of 72 in.-lb./cu. in., a deformation more than 50% higher, or 0·66% as against 0·42%. The diagrams of this kind, obtained with a dropping hammer of 3 lb. and 4 lb., are shown in Figs. 12B and C both loaded up to about 53 in.-lb./cu. in. By changing the weight of the hammer and by using

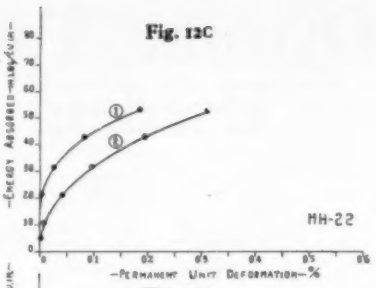


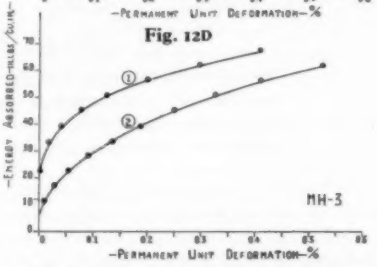






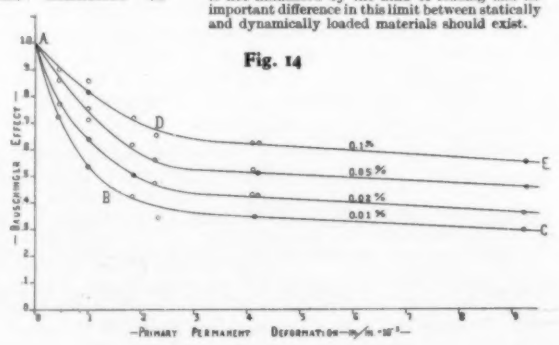
the same dropping height, say 8 in. and 16 in., the curves of Figs. 12D and E were obtained, showing slight differences in the permanent deformation as a function of the absorbed energy. From these diagrams, the diagram showing the influence of the loading speed in in./sec. as a function of the energy (in.-lb./cu. in.) absorbed, was calculated and recorded in Fig. 13. Starting from zero speed for the static tests, this diagram represents clearly the effect of the loading speed in relation to the





absorbed energy for the permanent micro-deformations of 0·004%, 0·01%, 0·02% and 0·05%. It can be seen by this diagram that, between the speed of 10 and 50 in./sec., the increase in energy to produce the same permanent deformation (0·004%) is of the order of about 55%. Compared to the static test results (zero speed) the increase of the elastic limit of this material under dynamic loads (speed 50 in./sec.) is even much greater. For higher permanent deformations (0·05%) this increase becomes somewhat smaller and drops to about 45% at 50 in./sec. These curves, showing little scatter and which follow in a nearly perfect manner the single test records measured at different speeds and varying permanent deformations, seem to indicate that the dynamic elastic limit, that is, the limit practically without any permanent elastic deformation increases in direct proportion to the loading speeds. Any reliable results about this point could not be found in the literature.*

* From a private correspondence with an outstanding authority in this field, the opinion was prevailing that the elastic limit of the material is not influenced by the kind of loading and no important difference in this limit between statically and dynamically loaded materials should exist.



Furthermore, the effect of Bauschinger, due to residual stresses of a previous torsion in the opposite sense upon duralumin specimens, is shown in Fig. 14. It can be seen that, considering the permanent deformation of 0·01% (curve A-B-C), the dynamic load which the virgin material can support is reduced to about 54%, if the specimen has suffered an initial permanent deformation of 0·001″/„ in the opposite sense; for a deformation of this kind of only 0·0005″/„ the dynamic elastic limit drops about 30% of that of a material without preliminary permanent deformation. Considering a permanent deformation of 0·1% (curve A-D-E), the reduction of the dynamic load is smaller and drops only 20% for 0·001″/„ permanent deformation, and 46% at 0·0092″/„ permanent deformation.

(b) Magnesium Alloy 57S

The results of these tests are shown in Figs. 15–19. This material seems to present somewhat more irregular results than duralumin. Of two specimens (X-12 and X-15) of two different bars, the static elastic limit in torsion was found to be, according to Fig. 15, about 3,600 and 5,500 lb./sq. in. at a permanent deformation of 0·0001″/„. The shear modulus was established as 2,860,000 lb./sq. in., compared to 4,090,000 lb./sq. in. for duralumin. Also the energy absorbed by these two specimens, represented as a function of the static deformation shown in Fig. 16, is very low; only a few in.-lb./cu. in. (3·4 and 1·8) are sufficient to produce a permanent deformation of 0·0001″/„ compared to about 23 in.-lb./cu. in. for duralumin.

One characteristic dynamic torsion diagram with magnesium alloy specimens, showing the permanent deformation as a function of the energy applied to the virgin material No. 1 and that applied to the pre-stressed specimens No. 2, is shown in Fig. 17. Here again the energy in in.-lb./cu. in., required to produce permanent deformations even in virgin material, is very low. Only about 3·6 in.-lb./cu. in. were needed to produce a deformation of 0·0001″/„, and practically no dynamic load is necessary to cause small permanent deformations in a material having undergone in a previous loading cycle a total permanent deformation of 0·00035″/„. Starting from zero, the curve No. 2 shows at 0·0001″/„ permanent deformation a dynamic load of 1·4 in.-lb./cu. in. The dynamic resistance of this material against small permanent deformations is only about one-tenth of that for duralumin. In Fig. 17b other test results of this alloy for a different total preliminary deformation are shown. Furthermore, tests of this kind with increasing speed and use of the same hammer, as well as at constant speed with increasing hammer weight, have been carried out; 1 in. dropping height under increasing hammer weight, and a ½-lb. hammer under uniformly increasing dropping height of 1 in., were used. The diagram of the influence of the loading speed on the results of the 0·01% permanent elastic limit is shown in Fig. 18. This material is also very sensitive to increase in loading speed, so in case we have an increase from 30–60 in./sec. the energy necessary to produce a permanent deformation of 0·01% is increased from 3·4 in.-lb./cu. in. to 5·8 in.-lb./cu. in., or an increase of about 70%. Compared to the elastic limit of 1·8 in.-lb./cu. in. at zero speed by this effect a 32 times higher value is reached at a speed of 60 in./sec.

The effect due to residual stresses locked up in the elastically overloaded specimen, is also very great. For a permanent deformation of 0·01% a dynamic load of only 80% is necessary, if the specimen has been previously put under a permanent deformation of 0·0001″/„; only about 46% of this energy is needed to produce a permanent deformation of 0·01% if the specimen has previously undergone a permanent deformation of 0·0003″/„; and for an initial deformation of 0·001″/„ only 16% of the original dynamic load is necessary to cause a deformation of 0·01%. In this respect the magnesium alloy is weaker than duralumin 24ST, for which as much as 54% of the original dynamic load is necessary to obtain this permanent deformation of 0·01% in the reversed sense.

This basic difference between these two light-metal alloys throws some more light on the importance of the "effect of Bauschinger" in the study of metals and alloys under dynamic loads. In all instances where dynamic torsion loads are applied to elements of construction, it is evident that the behaviour of the material used, with regard to these fundamental properties, should be taken into consideration in order to avoid any undesirable results in the use of these materials. To explain this fundamental difference in the behaviour of these two materials, it can be said that, among other questions

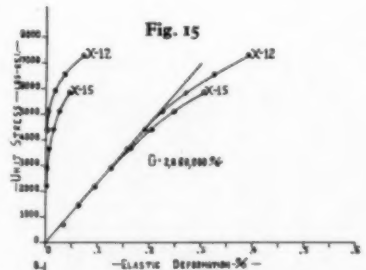


Fig. 15

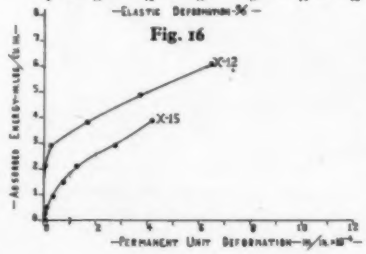


Fig. 16

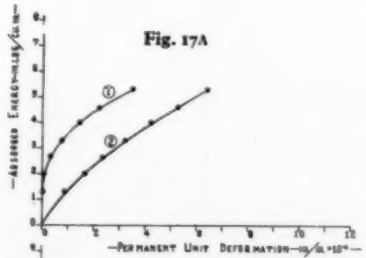


Fig. 17A

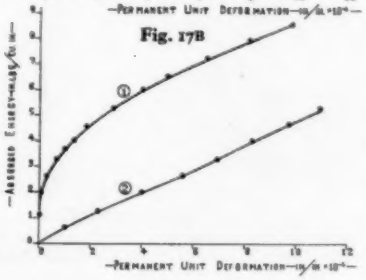


Fig. 17B

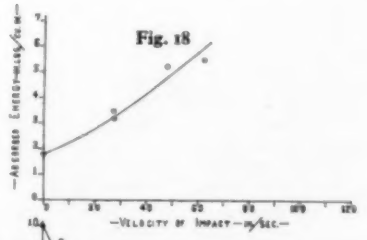


Fig. 18

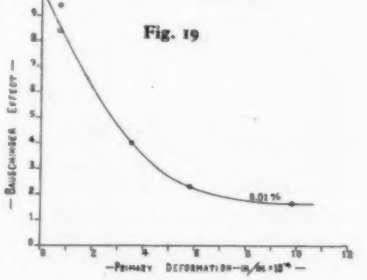


Fig. 19

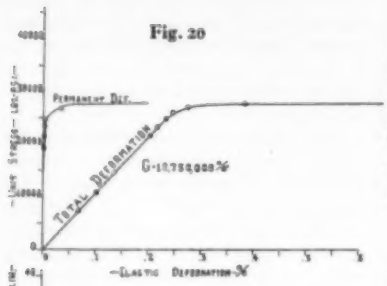


Fig. 20

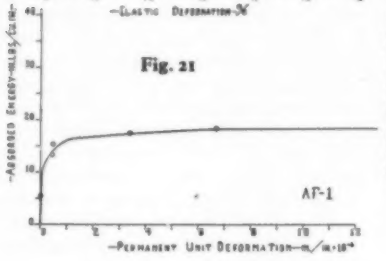


Fig. 21

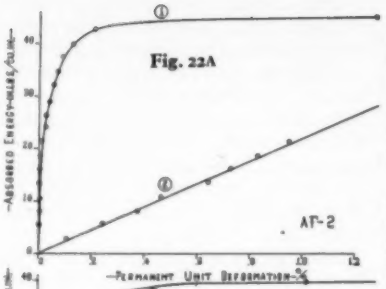


Fig. 22A

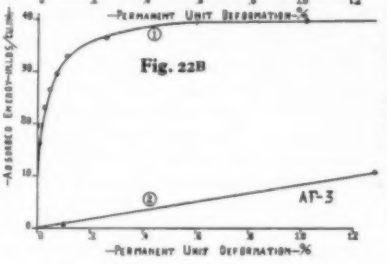


Fig. 22B

a closer study of the process of stress-hardening under plastic flow and the resulting values of the locked-up or residual stresses due to this stress-hardening, would be of greatest interest. In this investigation the important difference between these two phenomena has been only incompletely revealed; however, it seems to be of basic importance, in order to become acquainted with the dynamic behaviour of metallic materials, to carry out a more intensive study of the interrelation of stress-hardening and residual stresses produced under static and dynamic loads.

(c) Mild Steel

The elastic limit of mild steel under static torsion, according to Fig. 20, is about 25,000 lb./sq. in. and under a stress of 28,000 lb./sq. in. the total yielding of the material takes place. The shear modulus of elasticity has been determined with G = 10,750,000 lb./sq. in. According to Fig. 21, the energy necessary to produce the static deformation is about 10 in.-lb./cu. in. and about 16 in.-lb./cu. in. produce already an appreciable yielding of the material.

Under dynamic torsion loads of 1 lb. with increasing dropping height, records of the virgin material (curve No. 1) and of the cold-twisted material (curve No. 2) are shown in Fig. 22A. About 20 in.-lb./cu in. are necessary to produce 0·0001″/″ permanent deformation of the virgin material and 42–43 in.-lb./cu. in. are necessary to produce 0·002″/″ permanent deformation. After a torsion in one sense of 0·013″/″, that is practically up to the yielding of the specimen, no dynamic load is necessary to produce in the opposite sense noticeable permanent deformation. Half of the yielding load applied in the opposite sense produces already a very great permanent deformation of 0·01″/″.

Similar results are obtained by a preliminary torsion of 1·25% in one sense under a dropping height of 5 in. and an increasing load according to Fig. 22B. It is very characteristic that in the opposite direction (curve No. 2) this specimen is easily deformed permanently under very small energies.

The speed effect for mild steel, as represented in Fig. 23, for 0·01% and 0·004% permanent deformation, is very pronounced and an increase between the static elastic limit and the dynamic limit under a speed of 100 in./sec. is far over 100%.

The effect of Bauschinger, as revealed by this series of tests, is extremely great for mild steel. According to Fig. 24 a permanent deformation of only 0·0001″/″ in one sense is followed by a reduction of about 55% if tested in the opposite sense and a preliminary deformation of 0·0004″/″ reduces the energy of almost 90% to produce a permanent deformation in the opposite sense. Of the various investigated materials, this seems to be the greatest effect of Bauschinger measured.

(d) Nickel-chrome Steel

The static torsion test results of this material, which was tested in the annealed condition, are represented in Fig. 25. The shear modulus of elasticity has been determined as G = 11,300,000 lb./sq. in., and the static elastic limit of 0·01% permanent deformation is about 34,000 lb./sq. in. As shown in Fig. 26, the static energy absorbed, to produce these permanent deformations, is low; it has been shown that a few in.-lb./cu. in. produce a measurable permanent deformation. To produce a permanent deformation of 0·0001″/″ about 30 in. lb./cu. in. are necessary, and about 0·0007″/″ is attained at an energy expenditure of about 60 in.-lb./cu. in.

To be continued.

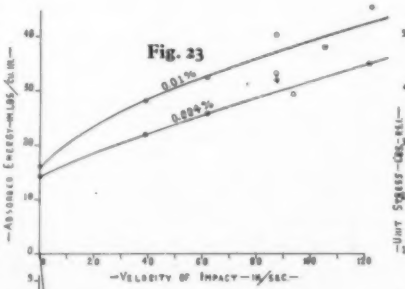


Fig. 23

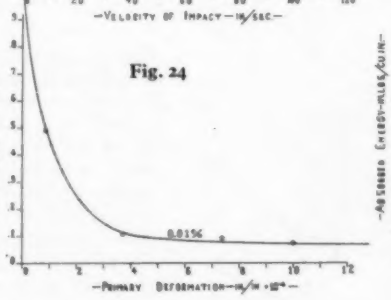


Fig. 24

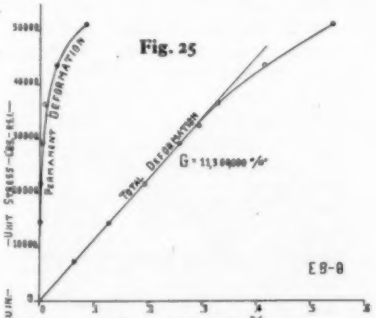


Fig. 25

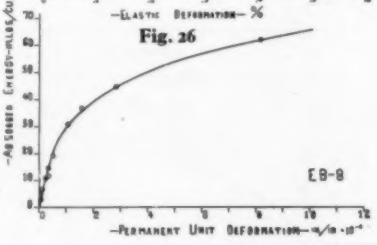


Fig. 26

Salt-Bath Brazing

A recent development of the brazing process uses salt baths for heating the joint to the brazing temperature. Some of the advantages of the method are discussed and information obtained as a result of development work on the subject is presented.

ALTHOUGH the term "brazing" originally referred to the jointing of such metals as copper and steel by means of the copper-zinc brazing alloys, the term is now used in a much wider sense, and such terms as "copper brazing" and "silver brazing" are in universal use.

The essence of brazing, as distinct from welding, is that the jointing alloy having a lower melting point than the metal or metals to be joined, the latter are not melted in the process. For a satisfactory joint, that surface of the component which will eventually form part of the joint must be clean and free from grease, oxide films, etc. It is essential, therefore, to avoid the formation of such films, at the relatively high temperatures involved in brazing, by the application of a suitable flux or by other means.

There are several methods of carrying out the process, differing in the method of heating to the brazing temperature and in the means of avoiding oxide film formation. In the oldest method, which still has a considerable field of application, a gas torch is used for heating and flux and brazing alloy are usually applied to the joint during the heating process. Dip brazing, as its name suggests, is effected by dipping the joint in a bath of molten brazing material which is covered with a layer of molten flux. In the remaining methods, the brazing alloy and flux, where necessary, are placed in position before the heating, which may be by furnace, H.F. induction, resistance or salt-bath equipment, is commenced.

Salt-bath brazing, with which we are concerned in this article, has much in common with dip-brazing, but it does not suffer from the disadvantage that the whole of the area dipped into the bath is covered with brazing alloy. In consequence, the amount of brazing alloy used is lessened and the necessity for cleaning off the excess is avoided. There are, too, certain types of work such as those illustrated in Figs. 2 and 3 which, because of their construction, are unsuitable for dip-brazing. In the salt-bath method, a relatively small amount of brazing alloy, in the form of wire, strip or granules, is placed within or near the zone to be joined. The work is then heated by a short immersion in a molten salt bath and subsequently cooled and washed. This method causes no scaling of the parts, and with a few preliminary experiments, it is easy to determine the correct amount of brazing alloy, for any particular joint, so as to avoid excess. These two features minimise finishing operations after brazing and, coupled with the speed and simplicity of the salt-bath method, result in lower costs. There is often a considerable saving in labour. Compared with torch and ordinary muffle-brazing, salt-bath brazing has the following distinct advantages:—(1) Speed of operation and greatly reduced labour costs; (2) accurate temperature control; (3) the scale-free finish requires less work in finishing operations; (4) several joints of a complicated assembly can be brazed simultaneously.

Some typical applications are illustrated in Figs. 1–3. The advantage of the simultaneous brazing of several joints will be appreciated by reference to Figs. 1 and 2, showing an assembly of copper tubes and mild-steel plates before and after salt-bath brazing with silver solder. The total time of immersion in the bath was 1¾ minutes at 780°–800° C. In Fig. 3 are shown two sizes of copper-contact bodies to which silver contacts have been salt-bath brazed using silver solder. It is noteworthy that a plant is operating which is specially designed for brazing a steel component in which the whole operation — preheating, brazing, quenching and washing—is performed automatically. It is illustrated in Fig. 4.

Materials

A list of suitable brazing materials is given in Table I. Three sizes of wire, 14, 18, and 20 S.W.G. are used in salt-bath brazing, 18 S.W.G. being the most common. Sheet and strip brazing materials are normally 0·002–0·010 in. thick (usually 0·002–0·004 in.). In certain instances granular brass is used.

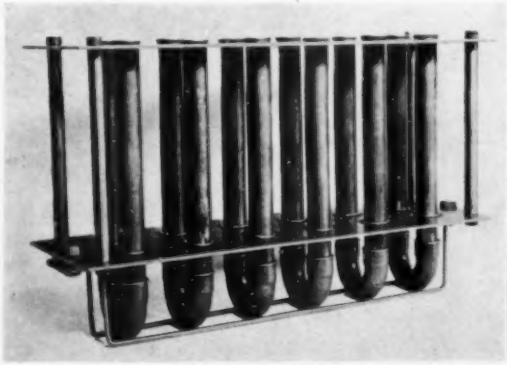


Fig. 1.—Copper tubes to be brazed together and into a mild steel plate by means of silver solder. Note rings of solder in position at the joints.

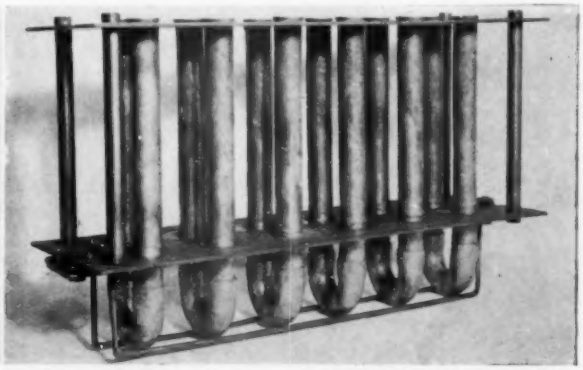


Fig. 2.—As Fig. 1 after immersing in molten sodium cyanide, at 780-800° C., for a total time of 1¾ minutes, followed by air-cooling and washing.

TABLE I.—EXAMPLES OF BRAZING MATERIALS AND TEMPERATURES EMPLOYED

Name	Copper %	Silver %	Zinc %	Lead %	Cadmium %	Melting Point °C.	Brazing Temperature °C.
Copper	Pure	—	—	—	—	1,083	1,120
Silver	—	Pure	—	—	—	960	1,000–1,020
Brass (B.S. 263 : 1931)							
Grade AA*	59–61	—	Remainder	0·50 max.	Total	890–900	920–950
Grade A†	53–55	—	Remainder	0·50 max.	Impurities	880–890	910–940
Grade B†	49–51	—	Remainder	0·50 max.	0·75 max.	870–880	900–930
Silver Solders (B.S. 206 : 1941)							
Grade A	27·5–29·5	60–62	9–11	—	—	690–735	770–800
Grade B	36–38	42–44	18·5–20·5	—	—	700–775	820–840
Grade C	14–16	49–51	15–17	—	18–20	595–630	680–710
A.S.T.M. Specs.							
Grade 1	52	10	38	—	0·50 max.	820	870
Grade 3	45	20	35	—	—	775	815
Grade 4	30	45	25	—	—	695	775
Grade 6	20	65	15	—	—	695	720

* Grade AA is supplied as slittings or wire. † Grades A and B are in granular form.

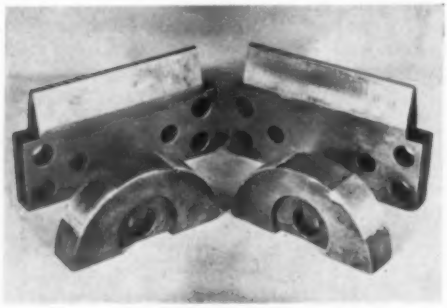


Fig. 3.—Copper contact bodies to which silver contacts have been brazed with silver solder in a cyanide bath.

Copper or silver brazing is used to join pure nickel, Inconel, Monel metal or stainless-steel parts, whilst brazing with brass is extensively used for steel parts. Silver solders are suitable for joining brass or other copper alloys or for brazing steel parts which must essentially be joined at low temperatures (for instance, in order to minimise distortion of delicate components). No flux is required when brazing with copper, silver or brass, but a flux containing a proportion of fluoride should be used with silver solders.

Joint Design

The design of joints is of considerable importance in salt-bath brazing, as indeed it is in any brazing operation. Close attention should be paid to the clearance between the parts to be joined. This should preferably be less than 0·005 in. on diameter, although satisfactory joints have been made with wider and rather variable tolerances. For the strongest joints, the figure should be 0·002–0·003 in. on diameter.

Experiments have been made with a design somewhat similar to joint A, Fig. 5, except that a ½-in. diameter steel bar was fitted into a similar size bore with varying clearances. The length of joint was ½ in. and brazing was effected in a cyanide bath at 950° C. using a brass wire applied externally. In Table II are given the loads to rupture for the various test pieces.

Five typical joint designs are shown in Fig. 5, with details of the method of applying the brazing alloy in each case. Joint A is best brazed by placing some granular spelter internally and a ring of metal externally, and joint B by applying wire externally. The wire is always placed above the joint so as to flow downwards when it melts. Alternatively, joints A and B can be brazed by making an internal recess in the collar, or by rolling a groove in the tube, and placing therein wire or strip. Joint C is best brazed by the use of internally-placed wire, as shown. Sheet or strip-brazing alloy is used for joints D and E.

Choice of Salt Bath

Cyanide baths containing 25–50% sodium cyanide are ideal for many purposes when brazing in the range 650°–950° C. They are used for brazing steel to steel with brass or silver solder and for joining brass to brass or copper with silver solder. Where steel parts are machined after brazing, "Cassel" P.S. 760 should be used as cyanide baths give steel a thin hard skin which is difficult to machine. P.S. 760 is ideal for brazing tungsten carbide to steel, for which cyanide is unsuitable.

TABLE II.—STRENGTH OF JOINTS WITH VARYING CLEARANCES

½ in. diameter bar brazed into ½ in. bore, with clearances stated. Length of braze—½ in. Brazed with externally applied brass wire in cyanide at 950° C.

Clearance on diameter (in.)	0·001	0·002	0·003	0·004	0·005	0·006	0·008	0·010
Load to rupture joint in tension (tons)	10·75	12·35	10·65	10·08	10·41	>9·7*	>7·4*	>8·35*

* The test piece broke in the collar, the joint remaining intact.

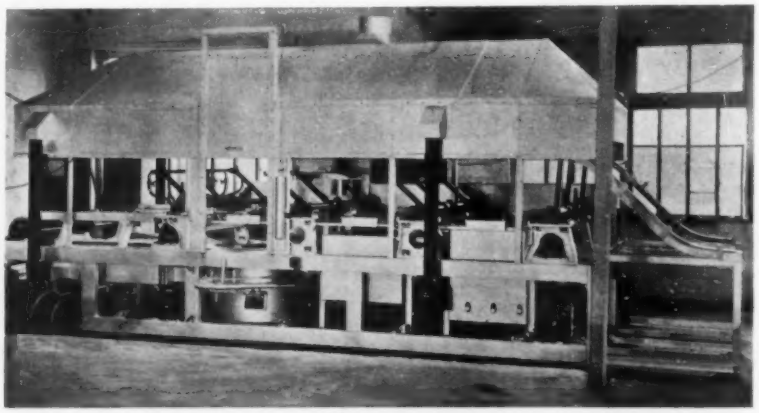


Fig. 4.—Automatic brazing plant. Transfer is direct from the cyanide bath used for brazing to a quenching medium. Finally the components are washed in hot water to remove salt.

"Cassel" H.T.900 is suitable for brazing in the range 900°–1,150° C.; alternatively "Cassel" "Carboneutral" No. 2 may be used from 970°–1,150° C. Nickel and high-nickel alloys are very susceptible to embrittlement by sulphur, and before using either of these high-temperature salts for brazing such material, any small traces of sulphur should be removed by suspending nickel turnings or scrap sheets of nickel alloy in the bath for 2 hours at brazing temperature.

Procedure

The parts are machined to correct limits, cleaned free from scale or heavy grease, and the brazing alloy placed in position, a fluoride flux being applied when using silver solder. The assembly is then warmed to remove moisture before immersion in the salt bath, which is

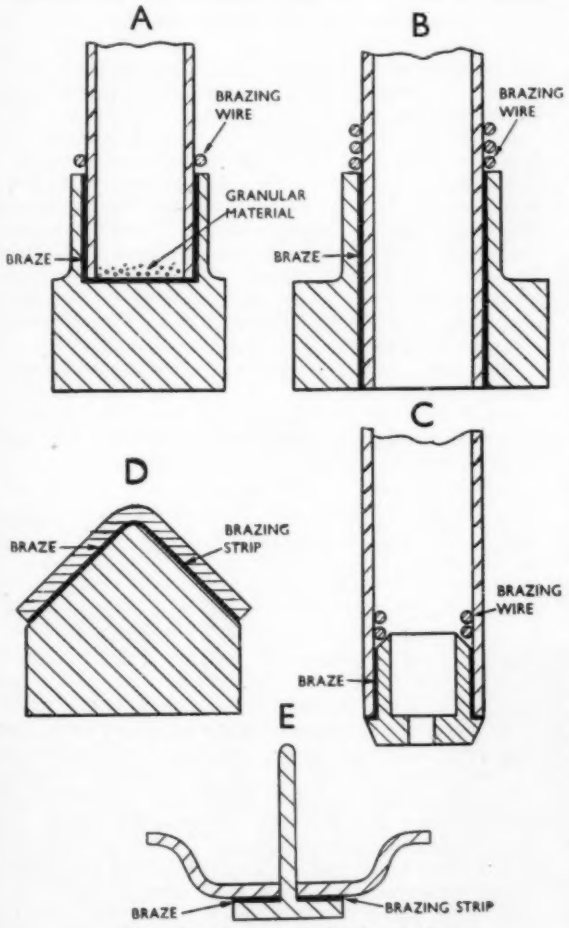


Fig. 5.—Some typical joint designs.

held—according to the alloy used—at the brazing temperature shown in Table I.

Joint designs D and E can be immersed in the salt bath immediately. With joints A, B, and C, employing external or internal brazing wire, it is necessary to heat the joint to brazing temperature before the wire melts, otherwise the brazing alloy will flow outside the part but not into the joint. This is easily done by first partially immersing the joint in the salt bath for a minute or two, leaving the wire just above the level of the bath. When the joint reaches temperature, the assembly is lowered to melt and flow the brazing alloy.

The whole operation is quickly carried out, the time varying from half a minute to four minutes, depending on the mass of the piece.

Usually, it is necessary to hold the parts in jigs for immersion in the salt bath and, as a little excess solder may braze the part to the jig, care is necessary in arranging the method of fixing. In cyanide-containing baths, satisfactory fixing can be effected by the use of jigs made of stainless steel which cannot be brazed in cyanide baths. Certain designs of joint are best tack-welded before brazing.

Parts brazed in H.T. 900 or "Carboneutral" No. 2 are preferably quenched in "Cassel" C.Q. 530 at 540°–600°C., followed by an air cool. This gives a better finish than cooling directly from the brazing temperature in air. Also, quenching in C.Q. 530 helps to remove salt after brazing. Air cooling can, of course, be used provided the finish is acceptable. Tungsten-carbide parts, after brazing, are also quenched in C.Q. 530 and then air cooled in order to avoid cracking. Cooling from cyanide or P.S. 760 salt baths is usually in air or oil. Very occasionally oil-quenching causes the joint to "blow" a little. Water quenching from the brazing bath is too drastic and tends to cause the jointing material to blow out or spatter, although it may be satisfactory in certain cases. Whichever method is used, the brazed part should always be allowed to cool well below the brazing temperature before quenching. Each job has to be considered on its merits and the handling procedure developed accordingly.

Care should be taken that the salt is not left trapped in blind joints. By having a particularly good fit, or by immersing the joint in the salt bath to the minimum possible depth, salt can sometimes be prevented from flowing, in appreciable quantities, into blind joints. Alternatively, such joints should be provided with a drainage hole to allow salt to run away after brazing.

With the exception of those which have no blind holes, and which have been water-quenched, parts must always be washed in hot water to remove salt.

Acknowledgments

We are indebted to the General Chemicals Division of Imperial Chemical Industries for much of the information contained in this article; also for the illustrations. A considerable amount of development work has recently been carried out on the subject, and the information presented is the outcome of this programme.

Constant Charge System of Cupola Operation

A BOOKLET has been published under the above title, which deals with the use of a standard charge so constituted as to produce an iron of constant composition. By the addition of suitable materials in practicable amounts, the metal can be modified in chilling characteristics, etc. so as to suit the whole range of castings normally produced by any particular foundry. Among these addition agents is the material "Nisiloy," which has only recently become available in Great Britain. This nickel-silicon inoculant is particularly effective in ensuring ready machinability in light sections. Copies of this useful booklet are available on application to The Mond Nickel Co., Ltd., Grosvenor House, Park Lane, W.1.

Separation of Cadmium from Large Quantities of Zinc

By C. W. Barker, M. Cahill, and R. S. Young

Rhodesia Broken Hill Development Co. Ltd., Broken Hill, N. Rhodesia

A procedure is described for the precipitation of cadmium from solutions of high zinc content by means of zinc dust in warm dilute sulphuric acid. The method has been found to give results faster than the usual method adopted.

THE chief difficulty in the determination of cadmium is the separation from its most common'y associated metal, zinc, especially where the latter is in large excess. Usually the separation is effected by successive precipitations with H_2S, in faintly acid solution, bringing down less zinc each time. With large quantities of zinc it is impossible to precipitate all the cadmium with H_2S at the acidity required to prevent zinc sulphide also coming down. Generally three, or even four, precipitations are necessary before the cadmium is free of zinc. The first precipitate, with a large quantity of zinc sulphide present, is very difficult to filter and wash. Subsequent separations, with increasingly smaller quantities of zinc sulphide, do not present any problem.

To improve this separation, we have adopted the industrial practice of precipitating cadmium with zinc dust to give in the first precipitation a small quantity of granular, easily filterable residue of zinc dust and cadmium. Two subsequent separations with H_2S yield a zinc-free cadmium sulphide. The conditions necessary for quantitative removal of cadmium with zinc dust have been established, and we feel this procedure is distinctly preferable to the former treatment of a large mass of gelatinous zinc sulphide which retained cadmium and was extremely difficult to filter and wash.

The procedure detailed below was developed for zinc sulphate solutions ranging in cadmium content from 0·01–1·1%. Other members of Group 2 were not present in significant quantities in these solutions, but if present they would necessitate the usual separations after isolation of cadmium. These would entail sodium polysulphide treatment to give Bi, Cu, and Cd, excess NH_4OH to separate Bi, and iron powder to remove Cu.

Procedure

To 1,000 ml. of zinc sulphate containing 0·01% cadmium, or a smaller sample for larger quantities of cadmium, add sufficient H_2SO_4 to bring the acid content to 0·2–0·5 gm. per litre. Add 1–2 gm. cadmium-free 325 mesh zinc dust and agitate with a laboratory stirrer at 110–120 r.p.m. for 1 hour, maintaining the temperature at approximately 50° C.

Filter by suction using Whatman No. 42 paper and wash the precipitate thoroughly with hot water. Transfer the paper and precipitate to a 400-ml. beaker containing 15 ml. of HCl, rinse the funnel and original precipitation beaker with 35% HCl, adding the rinsings to the main solution. Boil until solution is effected and filter, washing thoroughly with hot water.

Neutralize the filtrate with ammonia and re-acidify with HCl, to give an acid concentration of 5 ml. per 150 ml. of solution. Cool to room temperature and pass in H_2S for 30 minutes, adding water or dilute ammonia to the solution, if necessary, to ensure precipitation of all cadmium together with a fair amount of zinc. Filter and wash thoroughly with hot water. Dissolve the zinc and cadmium sulphides through the paper into the original beaker with hot 10% HCl, and wash the paper well with hot water.

Add 10 ml. 1 : 1 H_2SO_4 to the solution and fume to dryness. Cool, add 30–40 ml. water and 8 ml. 1 : 1 H_2SO_4 to the beaker, together with a little paper pulp. Boil to effect solution and cool. Filter through a small Whatman No. 42 paper into a 100-ml. measuring cylinder and wash until a volume of 90 ml. is obtained. Transfer to a 250-ml. beaker, wash the cylinder with 10 ml. water and add to the main solution, giving a total volume of 100 ml. Pass in a fairly slow stream of H_2S for 30 minutes. If cadmium sulphide is slow in coming down, add water in 5-ml. portions until precipitation commences.

Filter off the cadmium sulphide and determine cadmium by any standard procedure as Cd S, Cd SO_4, or electrolytically.

Discussion

The optimum conditions for the precipitation of small quantities of cadmium in the presence of large amounts of zinc were established by repeated trials on synthetic and plant solutions. Little difference in recovery was observed when the temperature ranged from that of the room to 85° C, but filtration was expedited when the solution was around 50° C. and this temperature was accordingly adopted. Agitation was varied from hand stirring for 1 minute every 5 minutes to high-speed mechanical agitation. The former gave slightly low results and a medium-speed mechanical stirrer giving 110–120 r.p.m. was finally adopted. Variations in time of agitation indicated that 30 minutes gave slightly low recovery, whereas no benefit was obtained from periods in excess of 1 hour, and the latter period is recommended. The inter-related variables of acid concentration and zinc dust were studied over a wide range, and it was found that 1–2 gm. zinc dust and 0·2–0·5 gm. per litre H_2SO_4 gave the best results. Acid concentrations in excess of 0·5 gm. per litre gave marked decreases in recovery of cadmium.

Summary

Precipitation of cadmium from solutions of high zinc content by means of zinc dust in warm dilute sulphuric acid, with agitation, results in a faster and more convenient separation than effected by the usual successive precipitations with H_2S and the filtration of large quantities of zinc sulphide.

A Recent Open Hearth Installation at Clydesdale Steelworks

THE decision of Messrs. Stewarts and Lloyds, Ltd., to develop their Clydesdale Works for the production of the wide range of seamless tubes required by British-owned oil companies abroad involved, as a first step, the installation of a 16-in. Pilger mill and the reconstruction of an existing open-hearth plant. The Wellman Smith Owen Engineering Corporation, Ltd. received the contract for the reconstruction of the open-hearth plant, the first stage being the installation of four new furnaces.

Many factors are involved in the design of open-hearth furnaces and in the present case close co-operation between the Wellman Smith Owen Engineering Corporation, Ltd., and the Technical and Development staff of Messrs. Stewarts and Lloyds, Ltd., resulted in the decision to use 60-ton furnaces with a number of unusual features. The entire steel output is required to be of high quality for tube making, so that design features had to ensure satisfactory operational practice from a metallurgical viewpoint. Rapid charging and melting, and fast working furnaces operating on minimum slag volume, were essential considerations, and particular attention was paid to atmosphere control and to economy in fuel consumption. The relatively small tube ingots are all bottom cast and, as well-defined teeming rates are necessary to ensure satisfactory billets, the casting conditions must be kept under strict control.

As a result of the need to develop the size and layout of the furnace components to give the best conditions of gas flow consistent with any restriction imposed by site limitations, the furnaces possess a number of unusual features when compared with contemporary open-hearth units. For instance, the regenerators, slag pockets and uptakes are much larger than has hitherto been generally accepted in the steel industry but, so far, the increased size has reacted favourably on the life and performance of these components.

Furnace Body

The laboratory of the furnace has been designed to give a hearth area, per ton of steel, of 7·08 sq. ft., with a maximum depth, from sill level, of 27-in. This arrangement was based on past experience in the production of tube steel, the object being to secure rapid melting whilst retaining control of the carbon.

The fully-sloped back wall is built of basic refractory, fully plated on the outside. The furnace bottom is also fully plated; the tapping and charging sides are bound with solid blooms which are rigidly fixed to the bottom beams and also to the transverse beams over the roof. Both front and back skewbacks are suspended from the rigid roof bracing, thus permitting free vertical expansion of the walls.

Port Ends

The sizes, inclinations and lengths of the ports, which are of the Venturi type, were developed with the object of securing good flame direction and of encouraging early and rapid combustion of the fuel. In addition a pronounced knuckle was also developed to assist in this aim.

The semi-circular gas port, 3 ft. wide and 1 ft. 6 in. high consists of a refractory lined water-cooled casing which extends the full length of the gas port structure and is arranged for easy withdrawal for renewal. The air port, located over the gas port, has a minimum free area of 39·2 sq. ft.

The gas and air uptakes, have free areas of 9·0 and 37·5 sq. ft., respectively.

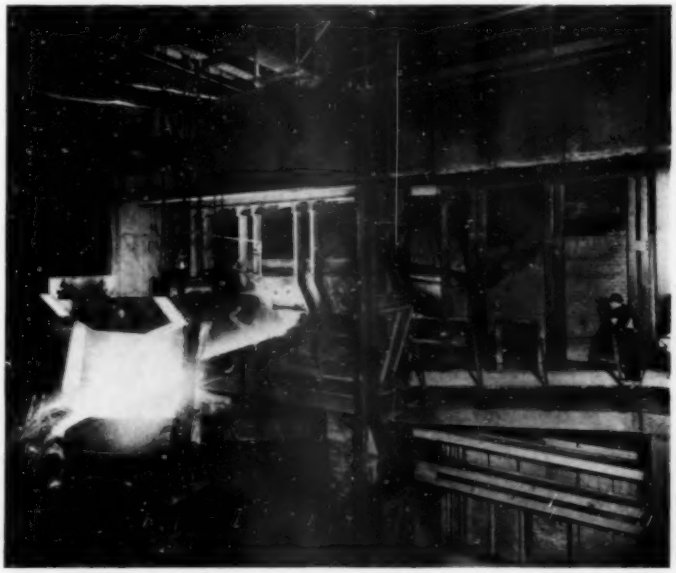
Slag Pockets

The slag pockets were designed to ensure a continuous run of at least 600 heats, the total holding capacity being 3,960 cu. ft. When one of the furnaces was taken off for roof repairs, after 400 heats, the slag accumulation in each air slag pocket amounted to only 67 cu. ft.

Regenerators

The regenerators are encased in mild steel plates, the sides, end and roof being insulated. The sides are supported at intervals by vertical joists rigidly fixed to a horizontal double joist framework.

The design is such as to give a checkerwork volume of 81 cu. ft. per ton of furnace capacity, the internal dimensions being 18 ft. by 13 ft. by 13 ft. deep, for the air regenerator and 18 ft. by 7 ft. 9 in. by 13 ft. deep for the gas regenerator.



Valves and Dampers

Each furnace has a 36 in. diameter mushroom-type isolating and regulating valve, connected by a firebrick lined main to two 36 in. mushroom-type water-cooled reversing valves which can be also used for regulation purposes, the regulating gear being situated on the charging stage. Before the isolating valve, a brick-built Venturi is provided for gas flow measurement.

The exhaust reversing valves in the gas flues are of the straight-through type and consist of water-cooled dampers and seats. The gas valves and dampers are operated by a 15 h.p. geared motor unit with suitable arrangement for regulation and fitted with the usual lost motion gear.

As in the case of the gas system, the air reversing valves are of the mushroom-type and the exhaust dampers of the straight-through type. Operation is by means of a 5 h.p. geared motor unit, fitted with an electro-mechanical brake. Each damper can be independently regulated.

The water-cooled chimney damper, operated by a 2 h.p. motor, is arranged to work in conjunction with a furnace pressure regulator. Provision is made for hand operation when required.

Gas and Air Supplies

Six 30 cwt. Morgan gas producers are arranged in two batteries of three units, each battery supplying gas to two furnaces. The gas mains are fitted with steam jets for cleaning purposes. The cleaning time of roughly four hours represents a considerable saving on the old method of burning-out.

Air for combustion is supplied by a fan capable of delivering 450,000 cu. ft./hour at 3 in. w.g., but provision is made for natural draught operation when desired. An orifice plate is installed in the inlet pipe for the purpose of flow measurement.

Instruments

The degree of instrumentation adopted is considerable, as may be seen from the list of instruments which includes, furnace pressure regulator and recorder, roof temperature pyrometer, indicating and recording gas and air meters, regenerator outlet temperature recorders, reversal signalling indicators, gas main pressure recorders and gas uptake pressure recorders. In addition, two Schofield immersion pyrometers are common to the four furnaces.

The instrument panel is housed in a well-lighted and ventilated dust-proof steel cabin which is mounted on the stage facing the furnace, with the control panel situated immediately in front of it.

Doors

All five charging doors are 3 ft. 9 in. wide, the three centre ones being 3 ft. 6 in. high and the two outer ones 2 ft. 8 in. high. The door frames are of welded construction and have separate cooling water supplies.

The doors are of hematite iron, lined with 4½ in. silica-brick, and have sill plates and fore plates which are also of hematite iron. The doors, which are fully balanced and fitted with electro-mechanical brakes, are raised by means of a 2 h.p. geared motor winch. Split sheaves fitted to the winding drum automatically prevent over-winding without the necessity of using limit switches.

Material Handling

The raw materials are brought on bogies from the adjoining stockyard to the charging stage, which has a track with suitable crossings immediately in front of the furnaces. The boxes are emptied by 5-ton High Ground Wellman chargers. Fast charging is of importance and it is interesting to note that in favourable circumstances charging times as low as two hours have been attained.

Furnace Performance

Each furnace was designed to produce 6 tons of ingots per gross operating hour at a fuel consumption of 5½ million B.T.U.'s per ingot ton ; furnace records show that the actual steel production and fuel consumption have been close to the design figures.

Hot Dip Galvanizers Association

THE Zinc Development Association announces the formation of the Hot Dip Galvanizers Association, a non-trading body which has been set up to promote the development of existing and new uses of hot dip galvanised coatings, and to improve galvanising technique.

The Council of the Association has elected Mr. F. C. Braby of Fredk. Braby & Co., Ltd. as its first Chairman, with Mr. A. H. Thompson of General Galvanizers Ltd. as Deputy Chairman. A strong Technical Committee, under the chairmanship of Mr. Thompson, has been appointed to deal with the important programme of scientific work which has been drawn up.

The new Association, which will be a Member of the Zinc Development Association, will have its offices at the same address, Lincoln House, Turl Street, Oxford ('phone, Oxford 48088), to which all inquiries and applications should be addressed. All general galvanisers may apply for Membership of the Association.

The Use of Inhibitors for Controlling Metal Corrosion

Part IV—Miscellaneous Inhibitors

By G. T. Colegate, B.Sc., A.I.M.

Following his treatment of chromates and dichromates, in the previous article, the author goes on to discuss the use of silicates, phosphates, sodium nitrite and vapour phase inhibitors. The use of more than one inhibitor and inhibitors used in acid pickling of steel are also considered.

The Use of Silicates

SILICATES have been recommended and quite extensively used in the treatment of water systems in laundries, hospitals, offices and dwelling houses. Like the chromates they are classed as dangerous inhibitors and if used in insufficient quantity may lead to intensification of attack rather than the reverse. As remarked by Speller,[1] it was found, about 1920, that silica was frequently present as a constituent in the rust coating on the inside of water pipes which had given relatively long service. Later, additions of silicates to corrosive waters was tried and found to be effective in reducing the attack on both the ferrous components and on any lead pipe that was in the system, the latter fact being of considerable importance in reducing the risk of lead poisoning with plumbo-solvent waters. The presence of silicates in the water leads to the deposition on the metal surface of silica in the form of a gel.

The amount of silica required to give optimum protection varies with the nature of the water. Speller states that to start with, 20 parts per million is generally adequate, though this may be reduced to about half after a month or two. The most suitable concentration for each water is best determined experimentally.

When the treated water is to be used for drinking or cooking purposes, the concentration of silicate should not be such as to give an alkalinity of more than 100 parts per million, otherwise the taste will become unpleasant and there may be some discolouration of food during cooking.

The effectiveness of silicates in some cases depends on their basicity—i.e., on the ratio of the soda to silica in the molecule, but this is an aspect of their use on which there are considerable gaps in our information. It is considered that silica treatment gives from 50–70% protection of ferrous metals from corrosion. It is most effective with soft and medium hard waters and though silicates will partially inhibit corrosion in pure water, the presence of calcium and magnesium carbonates is very desirable in assisting in the build-up of the protective coating.

Silicate treatment is particularly effective in hot water pipes, more so than in cold water systems. The method recommended by Speller of adding silicate to a hot water system differs from that for cold water systems. In the former case solid anhydrous silicate of soda is proposed, having a ratio of 3·3 silica to 1 soda. This material is packed into a suitable container and a portion of the water by-passed through it in order to maintain the desired concentration in the system as a whole. Solution is relatively slow and normally it is not necessary to refill the container oftener than once every 4–5 months.

A strong solution of sodium silicate is used for adding to cold water circuits. It has been claimed that for relatively acid waters a grade of sodium silicate having a ratio of 2·1 of silica to 1 of soda is preferable to the composition just mentioned.

In cold water systems, the silicate is best added in the liquid form since there is a tendency for cold water to deposit an insoluble coating on solid material which slows down the rate of solution very considerably. The design and location of treatment plant is of some importance since the effectiveness falls off with distance from the point where the addition is made. This falling-off being more marked with hot water than with cold, and in any case depending on the composition of the water. In any system containing a lot of pipe work it is frequently desirable to treat the water at more than one point. Failure to do this may lead to accelerated corrosion on the parts remote from the point of addition.

Silicate treatment of domestic water systems has been shown to be very effective in preventing "red-water." Generally, after a few weeks', or even a few days' treatment with silicate, the rust-laden water from taps, etc., has changed to a perfectly clear flow. In a domestic system the amount of silicate used annually is quite small, probably something of the order of five or six pounds per person per annum, or even less.

In the presence of chlorides, the concentration of silicate has to be increased. A similar increase was seen to be necessary in the case of chromates. The amount of knowledge available on the use of silicates in the presence of chlorides is not nearly as great as for chromates, and the exact concentration of silicate that requires to be maintained in any given chloride-containing system can only be determined by practical trials and experience. However, doubling or trebling the concentrations mentioned above will usually be sufficient in most cases, and it has been stated by Stericker[2] that even in brines there is no need to increase the concentration of silicate more than five times that given.

Silicate is recommended by the American Society of Refrigerating Engineers for use in fresh water recirculating cooling systems. The amount needed will depend on the plant in question and the water used, but to start with, 1½ gallons of water glass (40° Be) should be added per 1,000 gallons of water. This addition will normally cause the water to give an alkaline reaction to phenolphthalein, though this may not develop for an hour or two. If the required alkalinity has not developed a week after the addition, further quantities of water glass are required.

1 "Corrosion, Causes and Prevention" (McGraw-Hill), 2nd Ed., 1935.

2 *Ind. Eng. Chem.*, 1945, **37**, (8), 716.

The Use of Phosphates

Phosphates have been increasingly used in recent years for the treatment of water systems of various kinds and are useful in reducing the corrosion of iron and in controlling the deposition of calcium carbonate and iron oxide scales. The treatment of water systems by addition of small quantities of phosphates is known as the threshold treatment. The use of phosphates for preventing scale deposition is outside the scope of the present article, but besides this very important function, their action as corrosion inhibitors is also of considerable importance. Phosphates form an insoluble protective film on the surface of the metal and unlike the heavy film formed by carbonate deposition it does not interfere with heat transfer.

The dosage of phosphate required to give protection varies very considerably within the conditions. In stagnant systems, where the phosphate reaches the metal surface mainly by diffusion, much higher concentration is required than in a system under conditions of continuous flow. In the latter case, too, the velocity and type of flow will influence the rate at which the phosphate reaches the metal surface and therefore the rate at which the protective film is built up. Once a protective phosphate film has been built up, it will usually maintain itself for a limited period without the continued presence in the water of a dosage of phosphate, a valuable property in practice in those systems in which phosphate addition is not automatic. As in the case of other inhibitors already mentioned it is considered good practice to build up the protective film on the metal as soon as possible after the start of the treatment by using an initially high phosphate concentration.

The type of system and the relationship between the area of metal exposed and the volume of water coming into contact with it also influence the dosage of phosphate that is required to give protection. For example, in some systems as much as 20 parts per million of phosphate may be necessary, particularly if the circulation is poor, whereas in a system with considerable throughput of water, a fifth or even a tenth of this concentration would probably prove adequate. In some cases of large water distributing systems 1 part of phosphate per million has been shown to give good results. In the event of rust being present on the metal before the start of the treatment, the initial dosage of phosphate required may be considerable since much of it may get absorbed in the rust. In the same way, inadequate initial concentration of phosphate allows rusting to proceed at an appreciable rate during the build up of the film and much of the phosphate which might otherwise have been used for this build up is in fact absorbed with the rust as it is formed, thus slowing down considerably the process of film formation.

As in the case of silicate films, just mentioned, the temperature range over which phosphates are effective as inhibitors in aqueous media is appreciable. At higher temperatures, the amount of phosphate needed is more than at lower temperatures, as might be expected, but even in the region of 90° C. considerable protection is achieved by its use.

Similarly, unless the acidity of a water is particularly high, say above pH5, the effectiveness of phosphate is more or less independent of the pH value of the water.

Disodium phosphate is suggested by the corrosion committee of the American Society of Refrigerating Engineers as an alternative to chromates in the treatment of sodium brines in open systems. It is not as effective as chromate and needs more frequent renewal, but the reason for its being recommended is that chromates cause irritation to the skin of workers whose hands and arms come into contact with the brine and phosphates do not suffer from this disadvantage. The concentration recommended is approximately 100 lb. of phosphate to 1,000 cu. ft. of brine. A similar quantity of phosphate has to be added once a month in order to maintain the protective effect. It is standard practice to maintain the brine either neutral or slightly acid by the addition, if necessary, of hydrochloric acid. The phosphate is first dissolved in water and then added gradually to the system.

Hanlon, Steffen, Rohlich, and Kessler[3] studied the treatment of drinking water in U.S. Army posts, using among other things, various phosphates. They found that hexametaphosphates and heptaphosphates were useful in controlling scale formation, though less effective as inhibitors, particularly on black iron. On galvanised iron, their inhibitive effect was more marked. Whether these substances are likely to be of the same commercial value as the glassy phosphates normally used as corrosion inhibitors can only be judged after further investigation has been carried out.

3 *Ibid*, 724.

Treatment with more than one Inhibitor

Inhibitors are sometimes used in pairs instead of singly. For example, silicates and chromates, or silicates and phosphates, have sometimes been found to be more effective than an equivalent concentration of either. The theoretical reason for this is not clear and it is doubtful whether, in most instances, the advantage gained justified the additional control necessary to ensure the correct absolute and relative concentrations.

The authors mentioned above[3] investigated combinations of silicates with phosphates and found that the simultaneous presence of silicate gave improved results in some cases, but not in others. Organic inhibitors combined with phosphates were also tried, the addition of phosphate leading to an improvement.

A well-known instance of the effectiveness of two inhibitors used simultaneously is that of the use of metasilicate and chromate in inhibiting attack on aluminium.

The Use of Sodium Nitrite

Sodium nitrite is an inhibitor which is not as widely known or used as the others mentioned already; nevertheless it has been shown to be very effective in preventing or minimising the attack of waters on iron and steel. The precise method by which sodium nitrite functions as an inhibitor is not fully understood, though it has been suggested by Wachter and Smith[4] that it behaves as an oxidising agent and forms on the anodic parts of the steel a firmly adherent film of ferric oxide. It has also been suggested that it functions as a reducing agent and absorbs the oxygen present, thus preventing attack. However, the former theory appears the more likely. The concentration of sodium nitrite needed to inhibit corrosion in pure water is only about 0·005%. Sodium nitrite is effective in the presence of sodium chloride. Wachter[5] has studied the concentration required to give protection from corrosion in various concentrations of sodium chloride. It may be said that the concentration of the nitrite should be approximately equal to that of the chloride. Thus an 8% solution of sodium chloride requires at least 8% sodium nitrite to

4 *Ibid*, 1943, **35**, 358.
5 *Ibid*, 1945, **37** (8), 749.

prevent attack. These remarks apply to conditions under which there is no control of pH.

A further important characteristic of sodium nitrite as an inhibitor is that it is much more effective in alkaline solutions than in acid ones. Also, nitrite is effective on steel that is already rusted.

Besides being of interest in connection with the corrosion of steel, sodium nitrite has been shown to reduce the attack on a variety of other metals under certain conditions, notably aluminium, Monel metal and, at elevated temperatures, brasses.

Vapour-phase Inhibitors

The use of sodium benzoate in antifreeze solutions has already been mentioned. Vernon[6] also describes the use of the same material as a vapour-phase inhibitor. It was found that steel specimens wrapped in paper which had been soaked in a 5% solution of sodium benzoate and dried remained bright in a warm humid atmosphere, intermittently precipitating moisture, whereas similar specimens wrapped in untreated paper rusted rapidly. In addition to sodium benzoate a number of esters of benzoic acid were also tried as well as of materials related to benzoic acid.

The use of a n-butyl benzoate as a vapour-phase inhibitor in packaging work was shown by Vernon to have interesting possibilities, both for the protection of steel and aluminium. This, and similar esters of benzoic acid, are insoluble in water, and there is therefore, no appreciable tendency or them to be leached out, should saturation with water take place.

6 *J. Soc. Chem. Ind.*, 1947, **66**, 137–142.

Inhibitors for the Acid-Pickling of Steel

Inhibitors are probably more widely used in the pickling of steel than in any other way and have been for years. Many of the substances used for this purpose have been chosen as a result of practical experience and trial and error rather than as a result of scientific reasoning. More recently, however, considerable research has been devoted to the development of new and more efficient inhibitors for this purpose and there are many patents covering such susbtances. Inhibitors are used on a large scale in pickling of steel for galvanising, hot-dip tinning, electrodeposition, scale removal after heat-treatment, etc.

Most of the inhibitors used for this purpose are of the adsorption type and function chiefly by interposing a barrier between the acid and the metal. Some of them may function to some extent by raising the hydrogen overvoltage of cathodic areas on the surface or may be preferentially deposited on such areas. These inhibitors considerably decrease the amount of attack on the metal, but if they are properly chosen they do not appreciably reduce the rate of scale removal.

In choosing an inhibitor for a particular purpose, although published literature gives a good guide as to what is available and likely to be effective, it is very desirable to carry out careful trials under the conditions obtaining in practice, though a preliminary selection can be made by laboratory tests. There is a great deal of information available on the question of the relationship between the chemical composition and structure of pickling inhibitors and their effectiveness, and though this material is of considerable interest it is not easy to apply direct to practice.

Some of the materials used are colloidal in nature while others are water soluble.

Concentration of Pickling Inhibitors

The most economic concentration to be used in each particular case varies very greatly with the inhibitor and with the particular process. In most cases, the protection obtained increases with the concentration though the relationship is not linear, and the actual concentration used must depend on economic considerations, balancing cost of inhibitor with weight of metal saved by its use and also taking into account any reduction in the speed of pickling that may result from the use of additional quantities of inhibitors. The rate of consumption of different inhibitors varies quite considerably and is also an important consideration in their choice.

The concentration of organic inhibitor used in acid-pickling will depend on the degree of protection required. The more effective inhibitors will give 90–65% protection in concentrations as low as 0·01% or even below this, whereas others require to be present to the extent of 1 or 2%.

A Metallurgical Study of German Aircraft Engine and Airframe Parts—Vol. II

In fulfilment of a promise made to the Aero Components Sub-Committee of the Technical Advisory Committee, when the late Dr. T. Swinden was its Chairman, the second and concluding part of the report on German aircraft engine and airframe parts in book form is now published, similar to the copy of the first part published in 1943 and reprinted in 1944. This new report, which is now available, embraces the results of the further investigations carried out.

The work covered is really a summary of very extensive investigations which have been carried out meticulously and at great cost. Essential information arising from the study of components is presented in concise and readily assimilated form, and the text is supported by numerous illustrations which, in themselves convey valuable information to the initiated. Extensive tabulated data are also presented.

As in the case of Vol. I of this report, from the proceeds of which £500 has so far been credited to the Royal Air Force Benevolent Fund, we, the publishers, have agreed that the whole of the profits arising from the sale of Vol.II, will be credited to the same Fund.

Vol.II of this book comprises about the same number of pages as Vol. I, and is worthily bound. Although printing costs have risen since the publication of the earlier book, it has been decided to publish the new book at the same price, viz., 10s. 6d. net.

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A Method for the Rapid Photometric Determination of Tungsten in Steels

By A. A. R. Wood

A method is described for the absorptiometric determination of tungsten in steels. After dissolving the sample in a sulphuric-phosphoric acid mixture and fuming to convert the tungsten to a phosphotungstic acid, an aliquot is taken and to it are added sodium thiocyanate and stannous chloride in concentrated hydrochloric acid. By taking blank readings, interference from most metals is avoided; vanadium and molybdenum give slight colourations under the conditions described but may be accounted for by the use of a correction graph.

A METHOD was published recently[1] for the determination of tungsten in cast iron, which utilised the reaction of tungsten with a thiocyanate in the presence of stannous chloride. The tungsten was held in solution by tartaric acid, the solvent for the cast iron being hydrochloric acid followed by an ignition and fusion with sodium carbonate. Stabilised conditions for the production of the yellow tungsten thiocyanate were provided by the use of a concentrated hydrochloric acid solution (" 70–80% of the concentrated acid in the final reaction mixture "). On application of this method, low unstable readings were obtained and precipitation of a colourless salt occurred. A series was then prepared containing successively more dilute hydrochloric acid solutions, and with the slightly more dilute solutions, higher and more stable readings were obtained. It was noted that the hydrochloric acid used was 1·18 sp. gr. (36% HCl); assuming that the acid used by the original authors was 1·16 sp. gr. (32% HCl), solutions prepared using this acid also gave good results.

Since spekker acid[2] is a good solvent for almost all steels and furthermore, holds tungsten in solution, consideration was given to its use in place of the hydrochloric-tartaric acid and sodium carbonate process.

Experimental

A high tungsten content steel was taken, dissolved in spekker acid and an aliquot treated with thiocyanate and stannous chloride as usual. A dull green colour developed, the absorption of which was a fraction of that to be expected.

Spekker Acid Concentration.—A series of solutions was prepared as follows :—

Ten ml. of a sodium tungstate solution (0·5 g. of W. in 1 litre) was taken and varying volumes of spekker acid added; the beaker was heated until fumes of sulphur trioxide appeared, cooled and made up to 100 ml. with water. Ten ml. portions were then taken respectively and coloured up as usual. The results detailed in Table I show that a minimum concentration of spekker acid must be maintained.

TABLE I

Ml. of Spekker Acid	Difference Drum Reading	Colour
2	0·50	Yellow
5	0·29	Green
10	0·42	Yellow-Green
20	0·49	Yellow
40	0·48	Yellow

Hydrochloric Acid Concentration.—The above solutions showed a marked tendency to fading and the effect of hydrochloric acid concentration was re-examined. 0·05 g. of a 16% tungsten alloy was dissolved in 40 ml. of spekker acid, fumed and made up to 100 ml.; 10 ml. were taken and sodium thiocyanate and stannous chloride solutions added in the required amounts; after adding hydrochloric acid, the solutions were made up to 50 ml. with water. Measurements of colour density were taken at intervals and results are shown graphically in Fig. 1. A tentative method was formulated as detailed below.

Take 1 g. of steel (maximum weight of W = 0·001 g.) and dissolve in 40 ml. of spekker acid, oxidise with nitric acid and fume till sulphur trioxide appears. Take a 10-ml. aliquot, add 10 ml. of 7·5% sodium thiocyanate and make up to 50 ml. with stannous chloride (90 g. of $SnCl_2.2H_2O$ made up to 1 litre with 1·18 sp. gr. HCl). Stand for 30 minutes and measure the absorption.

Interference from Other Elements.—Most elements commonly met with were found to give colours due only to their respective salts and these could thus be easily accounted for by taking blank readings. Molybdenum and vanadium respectively gave excessive yellow and green colours; the error thereby encountered was eliminated by the use of correction graphs.

Dilution and Fuming.—The range of tungsten covered by an initial weight of 1 g. of steel was 0–1% and provision must be made for tungsten contents up to 20%. 1 g. of a 16% tungsten steel was taken, dissolved and made up to volume as usual. By taking a suitable aliquot and adding the appropriate quantity of spekker acid, a fresh solution was prepared in which the amount of tungsten was within the usual range. On colouring up with thiocyanate and stannous chloride, a greenish coloured solution was obtained. In order to investigate the effect of dilution, of boiling, and of fuming upon the initial steel solution in spekker acid, another series of solutions was taken.

A 0·5 g. sample of a standard 16% W steel was dissolved and fumed with 20 ml. of spekker acid. This was diluted to 200 ml. with water; 25 ml. portions were taken and 37·5 ml. of spekker acid was added to each to maintain acid concentration. They were then boiled or fumed, diluted to 100 ml., and a 10-ml. aliquot portion coloured up in the usual way. Details and results are shown in

TABLE II

Treatment of Steel Solution	Colour of Final Solution	Difference Drum Readings
Dilute to 100 ml.	Green	0.97
Raise to boiling and dilute to 100 ml. ..	Green	1·04
Boil for 15 mins. and " "	Green	1·05
Boil for 30 mins. and " "	Yellow-Green	1·06
Take just to fumes and " "	Yellow	1·23
Fume for 10 mins. and " "	Yellow	1·26

1 Westwood, W., and Mayer, A. *Analyst*, 1947, 72, p. 464.
2 Vaughan, E. J. " The Use of the Spekker Photoelectric Absorptiometer in Metallurgical Analysis." Monograph published by the Royal Institute of Chemistry, 1941, p. 9.

Table II. The experiment when repeated for another steel and for pure tungsten solutions, showed similar characteristics, and these were also observed when extreme concentrations of sulphuric and phosphoric acids were employed.

It is clear that the final colour is affected by the initial treatment of the phosphotungstic acid and either a green or yellow (or mixture of both) compound may be formed. By fuming the solution after any fresh addition of spekker acid, a solution may be obtained which will provide consistent results. Prolonged fuming, however, gives rise to slightly high readings.

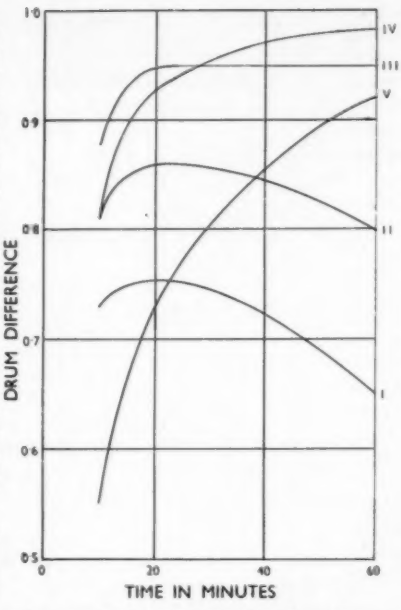

Fig. 1.—Effect of hydrochloric acid concentration (ml. 1·18 sp. gr. H Cl). I—35; II—32·5; III—30; IV—27·5; V—25.

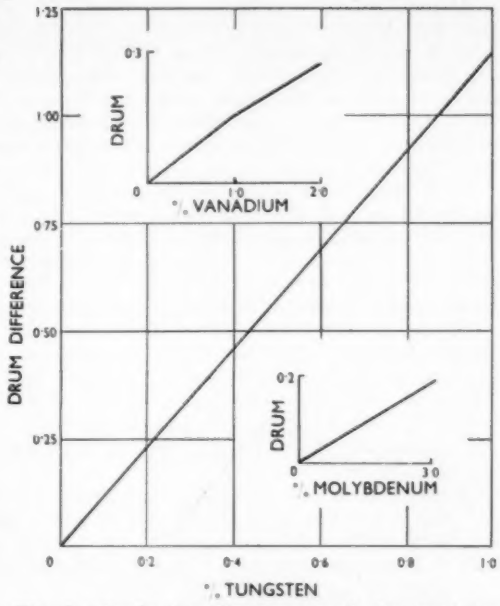

Fig. 2.—Typical calibration graph for tungsten with correction graphs for molybdenum and vanadium.

Temperature.—Under the given conditions, stability was attained between 20–25° C. Whilst at higher temperatures fading took place, at lower temperatures the solutions took longer to give a maximum absorption reading.

Method

Reagents

Spekker Acid.—Make up 150 ml. of phosphoric acid (sp. gr. 1·75) and 150 ml. of sulphuric acid (sp. gr. 1·84) to 1 litre with water.

Nitric Acid.—Sp. gr. 1·20.

Sodium Thiocyanate.—Dissolve 15 g. in 200 ml. of water.

Stannous Chloride.—Dissolve 90 g. in hydrochloric acid (sp. gr. 1·18) and make up to 1 litre with acid.

Tungsten Solution.—Take 1·2610 g. of pure, dry tungstic oxide (99·9% is available) and dissolve by warming with 20–30 ml. of water and 3–5 g. of sodium hydroxide. Make up to 1 litre with water.

Molybdenum Solution.—Take 0·2 g. of pure molybdenum (H.H.P.) and 0·8 g. of pure iron and dissolve in aqua regia. Make up to 100 ml. with water.

Vanadium Solution.—Take 0·385 g. of ferrovanadium (B.C.S. No. 205, containing 52·2% V) and 0·6 g. of pure iron and dissolve in aqua regia. Make up to 100 ml. with water.

Procedure.—For alloys containing up to 1% of tungsten take 1 g.; for higher ranges take proportionately less. Add 40 ml. of spekker acid, heat to dissolve and then add 5 ml. of nitric acid. Heat till fumes of sulphur trioxide appear, cool somewhat, dilute with water, cool to room temperature and make up to 100 ml. with water. Take two 10-ml. aliquot portions and treat as follows:

(i) *Blank Solution.*—Add 10 ml. of water and make up to 50 ml. with stannous chloride.

(ii) *Colour Solution.*—Add 10 ml. of sodium thiocyanate and make up to 50 ml. with stannous-chloride reagent, and adjust the temperature to 20–25° C.

TABLE III

Description of Steel	Tungsten added %	Blank Drum Reading	Colour Drum Reading	V correction Drum Reading	Mo correction Drum Reading	Final Drum Reading	Tungsten Range %	Absorptiometric Tungsten %	Tungsten Present %
B.C.S. 209. Stainless 18/8/1	0·90	1·03	0·60	—	—	1·03	0–1	0·89	0·90
B.C.S. 219. Ni-Cr-Mo. Mo = 0·61% ..	0·30	1·26	0·885	—	0·035	0·34	0–1	0·295	0·30
B.C.S. 224. Cr-V. V = 0·24%	0·50	1·26	0·595	0·04	—	0·265	0–1	0·54	0·50
Ditto	0·80	1·275	0·275	0·04	—	0·96	0–1	0·85	0·80
Ditto	—	1·275	1·19	0·04	—	0·045	0–1	0·04	Nil
B.C.S. 165. Cr-V. V = 0·29%	0·80	1·28	0·295	0·05	—	0·935	0–1	0·81	0·80
B.C.S. 220. Substitute H.S.S. Mo = 4·17%: V = 1·35%	—	1·295	0·475	0·025	0·025	0·77	0–10	6·70	6·74
B.C.S. 167. Alloy Steel. Mo = 0·55% V = 0·82%	—	1·30	0·365	0·01	—	0·925	0–20	16·0	16·12
B.C.S. 202. Ferro Tungsten	—	1·30	0·365	—	—	0·935	0–100	81	80·7

Absorptiometry.—Spekker photoelectric absorptiometer with drum setting 1·3; mercury vapour lamp with Ilford spectrum violet filters No. 601; 2 cm. cells.

Measure the absorption of both solutions after standing for 30 minutes and obtain a difference drum reading; then apply the appropriate correction for vanadium and molybdenum present in the steel. Read off percentage tungsten from a graph.

Calibration Graph.—Run from a burette 1, 2, 3, etc., up to 10 ml. of the sodium-tungstate solution into beakers containing 40 ml. of spekker acid. Heat till fumes of sulphur trioxide appear and then proceed as above. For the correction graphs, take 2·5, 5·0, 7·5, and 10-ml. portions respectively, of the molybdenum and vanadium solutions, and add 40 ml. of spekker acid. Heat till fumes of sulphur trioxide appear and then proceed as above. A typical graph is shown in Fig. 2.

Notes

1. Care should be taken to remove the beaker from the hot plate when fumes of sulphur trioxide first appear.
2. When it is not convenient to reduce the initial weight of sample, an aliquot may be taken, spekker acid being added to maintain the concentration and the whole solution fumed down before making up to volume.
3. The colour solution should be swirled thoroughly while adding reagents.
4. The same calibration graph is used for all ranges of tungsten and the range of the correction graphs is then adjusted accordingly.

Table III shows the results obtained on a number of steels, some containing tungsten and others with added amounts. B.C.S. 224 gave a slightly high, unaccountable result, and it is assumed that it contained a small amount of residual tungsten. The accuracy for a given range is ±1·5%, and the time for analysis is comparable with other photometric procedures. The method may be included in a composite scheme.[3]

Summary

The reaction between a tungstate and a thiocyanate in the presence of a reducing agent has been adapted for use as an absorptiometric method for the determination of tungsten in steel. Dissolution is with a sulphuric-phosphoric acid mixture, which keeps tungsten in solution as phosphotungstic acid. This is then coloured up with sodium thiocyanate and stannous chloride in a medium of concentrated hydrochloric acid. The yellow colour is corrected for interference from most other metals by taking blank readings; vanadium and molybdenum form slight colourations under the conditions described, but may be accounted for by the use of a correction graph.

Acknowledgment

The author wishes to thank the Directors of Messrs. Wild-Barfield Electric Furnaces, Ltd., for permission to publish this paper.

3 Haywood, F. W., and Wood, A. A. R. "Metallurgical Analysis by Means of the Spekker Photoelectric Absorptiometer." Adam Hilger, Ltd., London, 1944, p. 74.

Phosphor Bronze Co. Ltd.

We are informed that the correct postal address of the new Birmingham premises of The Phosphor Bronze Co., Ltd., is 286/292, Bradford Street, Birmingham, 5.

Correspondence

Gaseous Annealing of Whiteheart Malleable Castings

The Editor, Dear Sir,

In your January issue there appeared an article by Dr. J. E. Hurst on the subject "Ironfounding and the Metallurgy of Cast Iron" in which a small section was devoted to the gaseous annealing process for whiteheart malleable castings.

In this section, the statement is made that "the essential feature of this process lies in the controlled decarburisation of the white iron castings by annealing in a gaseous atmosphere of controlled composition. The most readily available sources of such gas mixtures are produced by the partial combustion of fuel gases such as town's gas, producer gas, or carburetted water gas,"

It is true that early development work on gaseous annealing was carried out, using atmospheres of partially combusted fuel gas, and that for experimental or pilot scale operation these remain the most convenient type. For production scale annealing, however, they are emphatically not the best solution. Very large volumes of atmosphere gas are required, and the operating costs, if mixtures derived from fuel gases are employed are consequently high. In the latter case re-circulated atmospheres of the "self-generated" type, i.e., in which the desired gas mixture is obtained by reaction of air or steam with the carbon content of the castings, are much to be preferred on economic grounds.

To the best of the writer's knowledge, all production gaseous annealing furnaces installed both in this country and abroad, employ the latter system.

Yours faithfully,

P. F. Hancock,
Chief Metallurgist.

Birlec Ltd.,
Erdington,
Birmingham, 24.
Feb. 28, 1949.

The Editor, Dear Sir,

Many thanks for sending a copy of Mr. Hancock's comments on the section in my article dealing with gaseous annealing process for whiteheart malleable castings. It was quite an oversight on my part not to refer to the industrial uses of gaseous re-circulated atmospheres of the self-generated type, and I do appreciate attention being drawn to this by Mr. Hancock.

Obviously this is a matter of considerable importance in the commercial development of this gaseous annealing process, and ought to be brought to the notice of your readers.

Yours sincerely
J. E. Hurst.

Bradley & Foster Ltd.,
Darlaston, Staffs.
March 3, 1949.

Marine Application of Gas Turbines

An agreement has been concluded between Messrs. W. H. Allen Sons & Co., Ltd., of Bedford, and The Bristol Aeroplane Co., Ltd., for collaboration on the application of gas turbines for Marine auxiliary purposes and in the industrial field, and for the exchange of information on aeronautical and industrial turbine problems.

Clad Steel Plate

By F. R. Pattison

Clad steel plate is the term applied to a composite plate composed of steel plate to one or both sides of which is uniformly bonded or joined a layer of corrosion- or heat-resisting metal the thickness of which is a substantial proportion of the total plate thickness. Applications for clad steel have developed and production technique has made appreciable advancement in recent years. Manufacture and applications were discussed by Mr. Pattison at a recent meeting of the Midland Metallurgical Societies and this article presents his views on the subject.

CLAD steels may be divided into two main classifications: homogeneously bonded plate and non-homogeneously bonded plate. Probably the greater tonnage produced commercially is of the first category. Methods adopted in the production of such plate vary, but the results in service vary little so long as the bond between the backing and cladding materials is integral and the thickness of cladding is uniform. The principal methods of producing homogeneously bonded clad steel are given in the following notes.

Homogeneously Bonded Methods

Casting method. Two corrosion resisting alloy plates are cleaned and ground and one face of each is coated with insulating material. The coated faces are placed together and edge welded. The insert so produced is placed in a mould and special analysis mild steel is poured in, completely covering the insert and producing a composite ingot which is then rolled down to size. The four edges are then sheared back to the point where the alloy cladding begins, thus producing two plates of clad steel from each ingot.

Inter-melting. Billets of carefully cleaned and prepared steel are placed in refractory moulds in such a manner that a space exists between the billets and the refractory walls. The mould is heated to a carefully controlled temperature and into this space round the billet the cladding material, for example, copper may be poured. The copper welds to the steel and the product is further processed by rolling, etc.

Fusion welding. A heavy slab of steel is laid flat, removable plates being placed at the sides so that they project beyond its upper face, their projections thus forming the sides of an open-ended box of which the slab is the bottom, or a separate shallow pan of thin gauge low carbon steel may be laid on the slab. The box so formed is then filled with powdered or small size metallic material of the composition desired for cladding, and slag which, when fused, will produce the desired cladding material. Heat is applied either by gas or electricity and the temperature raised sufficiently to cause fusion; at the same time the cladding is welded to the backing metal. In a variation of this method the slab is heated to approximately 800° C. and a carbon arc welding operation carried out from end to end of the alloy surface. After removal of the side plates the composite slab is rolled to thickness and size.

Arc welding. Welding rods made from the desired cladding material are used to deposit beads upon the backing metal, one bead being deposited upon another until the desired thickness is obtained, after which the usual rolling operations are carried out.

Resistance welding. One or more sheets of the cladding metal are placed upon steel backing and resistance welded by overlapping spots or seams after which further processing by hot rolling may be carried out

Bonding with heat and pressure. By far the greater tonnage of clad steel is produced by this method, but there is some variation in technique. The principal method involves careful preparation of the individual components prior to assembly. First, the surfaces to be bonded are carefully cleaned, generally by machining, then if stainless steel or Inconel is to be used as the cladding material, electrolytic nickel-plating is carried out to ensure a good bond. A nickel-chromium alloy, such as stainless steel oxidises too rapidly to bond directly to steel without the intermediate nickel-plating. Nickel, on the other hand, is not readily oxidised, is soluble in steel and has been found to be the most satisfactory of all the materials used for this purpose. Nickel also acts as a buffer to carbon migration from the backing steel, thus assuring greater bond strength and similarly, better heat transfer properties in the clad plate. After the components have been carefully prepared according to requirements, they are assembled in a pack or sandwich and precise control is exercised over the proportion of the components which make up this assembly. For steel plate, clad on one side only, the general procedure is to take a heavy slab of steel and clean one of its flat surfaces, either by slot blasting or machining and upon this face is then placed the slab of cladding material, also with one face carefully cleaned, so that the two clean surfaces are adjacent. Then a second similarly prepared assembly of steel and cladding material is placed on the top of the first one so that the two layers of cladding material are next to one another, but separated by an infusible parting compound. The steel backing plates are made slightly longer and wider than the cladding plates so that after the sandwich is formed there is a groove running around four sides of the assembly. Spacer bars are used to fill in the sides between the slabs and the whole pack is then completely welded, either by hand method or by automatic welding machine. This welding completely seals the pack to prevent contamination or movement of the components during subsequent heating and rolling. The sandwich is then heated to a temperature of around 1,150° to 1,300° C., depending upon the cladding, and this is rolled out on a heavy plate mill. The heavy rolling pressure exerted on the composite pack reduces its thickness uniformly and permanently bonds the cladding to the steel. During rolling the relative proportions of cladding material to steel in the assembly are not seriously altered, but experience indicates the proportions which should be used to give the right cladding thickness on the finished plate. After rolling, the pack is sheared or flame cut inside the weld edges as close to the edges of the cladding as possible. The pack is then

separated into two clad steel plates. In the manufacture of double clad material, the same general method of assembly is used but either a 5-ply pack or a 7-ply pack may be adopted. The clad steel plates so produced may then be supplied either in the " as rolled " condition, descaled by sand or grit blasting or, as in America, they may be de-scaled by the sodium hydride process.

Non-homogeneously Bonded Methods

Non-homogeneously bonded plate generally consists of a thin covering or lining of the corrosion resistant metal attached to a heavier steel plate by welding, using either the plug, spot or stitch welding methods. Clad plate so produced is not in the practical sense bonded all over the surface and whilst satisfactory for many applications, it may not be desirable for the fabrication of equipment which is to be under vacuum, or again the air space which exists between the two layers may be detrimental, especially if heat transfer through the clad plate is an important factor.

Development of Clad Steel

The first large scale development of clad steels commenced in 1930 and under the joint efforts of the International Nickel Company Inc. and the Lukens Steel Company very satisfactory nickel clad steel plate was produced. It was natural that nickel should be selected as the most promising of the corrosion resisting materials capable of being bonded to steel because nickel possesses good resistance to oxidation and is soluble in steel. Similarly, the first satisfactory commercially available clad plate in this country was nickel-clad steel produced by Guest, Keen, Baldwins Iron and Steel Co., Ltd., now The Steel Company of Wales, Ltd. Nickel is still regarded as the most satisfactory of all the materials used for clad steel, but, since nickel cannot be used under all corrosive conditions, it was necessary for further experimental work to be carried out on the use of other alloys, and now many clad plates are available including straight chromium steels ; chromium-nickel austenitic stainless steels, with and without molybdenum ; nickel ; Monel ; Inconel ; 70/30 cupro-nickel ; copper and silver.

Applications

Clad steels are used principally for corrosion resisting or heat resisting applications. In the majority of cases the question of cost determines their use, although there are some circumstances in which clad steel is justifiable on technical grounds. Clad materials can be more severely drawn in one operation than, say, solid stainless steel, which would require many intermediate anneals. Similarly, in some applications, in which maximum heat conductivity is essential and where a corrosion resisting surface is necessary on one side, the use of clad material is employed with excellent results. For instance, Inconel clad or stainless clad steel are both better conductors than solid Inconel or solid stainless steel respectively. Copper or silver may be used as the cladding materials because they are better conductors than the backing steels. There are too, applications where the materials joined in clad steels have characteristics which are particularly suitable for a product under consideration. For instance, certain types of domestic equipment may be desired with a corrosion resisting surface inside, whilst the outside is capable of being porcelain enamelled to match other parts of the unit. From the fabricators point of view one other big advantage of the clad steels is that they are, in general, available in plates appreciably larger than the solid cladding materials themselves.

The chemical industry in particular frequently requires processing equipment having at least one surface which is resistant to corrosion, and this may be desirable for one or several reasons, namely, to prolong the life of the equipment, protect the quality of the products, reduce maintenance costs, avoid frequent shut-down for repairs, or to enable cleaning or sterilizing to be carried out easily. The availability of equipment made from corrosion resisting alloys has reduced very considerably the dangers from metallic contamination which, in the case of foodstuffs, might be harmful, and in the case of some reactions may in fact make control of the process impossible, due to the fact that many metals exert a catalytic influence.

Factors Connected with the Use of Clad Plate

For the production of equipment to withstand corrosive conditions the first problem is that of selection of the best and most economical metal and in this connection the following factors affect the corrosion rate, namely type and concentration of corrodant, temperature, degree of aeration, rate of flow and presence of impurities.

A considerable amount of corrosion data from tests carried out both in laboratories and under plant conditions are available from most manufacturers of metals and alloys, and in addition, service records are frequently available on equipment which has been operating under the same or similar conditions. It is, of course, quite obvious that the most reliable corrosion information is obtained from tests conducted in production equipment under actual service conditions. In the design and fabrication of processing equipment this proper selection of materials is the most important single factor in obtaining satisfactory service. No single alloy or metal has yet been found which is capable of resisting all types of corrosion and therefore the particular properties of each material have to be carefully considered. In this connection, it is important to realise that the material having the lowest corrosion rate is not necessarily the most economical material and cognisance must be taken of this fact in selecting the metal or alloy to use.

Principal Properties of Cladding Materials

The straight chromium steels are, in general, typified by good resistance to corrosion, especially against highly oxidising conditions, they also possess good resistance to oxidation at high temperature. The chromium nickel austenitic steels are available in several types and find wide application for many chemical processes and for sanitary uses and certain elevated temperature applications. The molybdenum containing austenitic steels possess in general a high corrosion resistance and are reputed to be less susceptible to pitting or pin-hole corrosion than the regular 18/8 types, when exposed to such corrosive media as sulphuric and sulphurous acids, sulphite solutions and certain cellulose solutions. Nickel, with its superior resistance to hot concentrated caustic soda is used as cladding material for many types of equipment used in the alkali, rayon, soap and similar process industries.

Heat conductivity of nickel is high, therefore nickel clad steel is good for both heating and cooling. Nickel

should not, however, be used in contact with nitric acid or other highly oxidising acids or salts. Nickel retains its mechanical properties in sub-zero ranges.

Inconel, which is an alloy of nominal composition, 80% nickel, 14% Chromium, 6% iron, combines the qualities of nickel with extra resistance to heat and oxidation conferred by chromium. Inconel is free from intergranular deterioration at high temperatures, and because of its high nickel content it possesses excellent resistance to corrosion by alkaline solutions and to reducing conditions. Inconel is superior to both nickel and Monel in its resistance to alkaline sulphur compounds and hydrogen sulphide at both atmospheric and elevated temperatures. It is particularly useful in the production of fatty acids, dyestuffs, pharmaceuticals, edible oils, fruit juices, etc.

Monel is the other high nickel alloy which is frequently used as a cladding material and may be regarded more in the nature of a general purpose alloy with the strength and toughness of structural steel. Monel is especially useful for use in contact with common salt, dilute acid and strong caustic soda. It is not, however, resistant to certain oxidising materials such as nitric acid, sulphuric acid or ferric chloride.

For the base metal in the production of clad steels, carbon steels or other mild steels including certain low alloy steels, may be used.

Fabricating Clad Plate

In order to avoid damage to the clad surface, it is important that great care should be exercised both during fabrication and in subsequent handling. It is frequently advisable for fabricators to avoid surface contamination by protecting the clad surface with paper applied with paste or alternatively certain plastic coatings have been used and sprayed on to the clad surface. When such plastic coatings are used they must, of course, be stripped from the edges to be welded.

Clad steels should be in the annealed condition before severe bending or rolling operations are undertaken. Radii should be as large as possible and allowance made for spring back. All working surfaces of both plate and machines should be kept free from loose scale and steel particles or chips. Where necessary, rolling or other forming operations such as dishing may be carried out hot, but care must be taken to ensure correct heating conditions. Fuels high in sulphur should be avoided, especially for the high nickel alloys and direct flame impingement is undesirable. The atmosphere varies, depending upon the cladding, but in general a reducing atmosphere—if sulphur free—is preferable for the high nickel alloys, but should be avoided for the stainless steels.

Since clad steels are generally selected for the corrosion resistance of the cladding, care must be taken to ensure that the equipment being fabricated is soundly constructed. Metallic arc welding using the correct type of coated electrodes is almost universally adopted for joining clad steels—gas welding is seldom used and atomic hydrogen only on light gauge plates. Since the weld joining clad steel plates becomes an integral part of the equipment, it must not only be sound structurally but must be, as far as possible, as corrosion resistant on the clad side as is the cladding material itself.

Institute of Metals

Annual General Meeting

In connection with the Annual General Meeting, to be held in London from March 30th to April 1st, a Dinner Dance has been arranged for the evening of March 31st, at the Savoy Hotel. The principal guest will be the Rt. Hon. Herbert Morrison in his capacity as President of the Committee of the Privy Council for Scientific and Industrial Research.

Back Issues of Publications

A general index to Volumes I to X (New Series), 1934–1943, inclusive of *Metallurgical Abstracts* is now being set in type. There will be a considerable delay before this book is printed, but, in the meantime, members who do not possess the whole of the series (vols. I to X) are recommended to obtain an estimate for completing their sets at reduced rates. These ten volumes with the index will be invaluable for reference to the world's literature of general and non-ferrous metallurgy for the period that they cover.

Contents List of Publications

A revised Contents List of Publications (Miscellaneous Publication No. 4) has just been issued, price 3s. 6d. post free, to non-members and 1s. 9d., post free to members. This 57-page booklet lists, volume by volume, the contents of the 74 volumes of the "Journal" issued from 1909 to 1948, inclusive, and has an author index. It will be found to be a quick means of reference to the papers published by the Institute.

Accident Prevention in Chemical Laboratories

A chemical laboratory is a dangerous place. An accident which would be simple anywhere else may, in a laboratory entail serious consequences. The risk of accidents is greater when newcomers, lacking the practical experience of the older worker, carry out operations without clear knowledge of the hazards involved.

"Safety Measures in Chemical Laboratories" published recently for the D.S.I.R. by H.M.S.O. price 6d. (20 cents U.S.A.) by post 7d., covers the main causes of personal injury and material damage. The booklet was originally designed for the guidance of new staff at the Chemical Research Laboratory. After it had been prepared for internal use it was considered that it might be of value in a wider field.

The constantly widening scope of chemical science makes it impossible to include all the risks, but it is hoped that there will be much to refresh the memories of even senior research workers. The booklet contains sections on general laboratory operations and the use of apparatus, fire risks and burns, dermatitis, electrical hazards and shock, poisons, poison gases and the treatment of affected persons.

Appendices give some details of the Laboratory's safety organisation, which include the appointment of a part-time safety officer for the laboratory as a whole, sectional safety officers for each of the main research groups, and accident prevention lectures for junior staff. The standard form used for the reporting of accidents is also given.

Meeting High Performance Demands in Engineering Construction with Meehanite Metal

By A. Campion, F.R.I.C.

Engineering developments have created a demand for higher and more uniform strength properties in iron castings and much research work has been carried out, not only to produce a material of greater strength but of consistent dependability. Many processes have been developed and the progress achieved is not yet fully appreciated by engineers, it is of interest, therefore, that a successful process was discussed by Mr. Campion in a recent lecture at the Engineering Centre, Glasgow, with Sir John Duncanson as chairman, in which he referred to Meehanite as the result of many years' concentrated research, resulting in what he regards as the greatest advance yet made in the metallurgy of cast iron. Much of the information and data he gave in his lecture are presented in the following article.

MODERN engineering progress in the use of higher speeds, temperatures and pressures is making increasing demands on materials and components. To meet this demand there has been considerable development in materials and in fabricating technique to make the best use of them. This progressive trend is especially noteworthy in the case of cast iron on which much successful research work has been carried out. Early processes devised for improving the strength characteristics of this material, however, suffered from the lack of a method of a precise control of the size, form and distribution of the graphite within a wholly pearlitic matrix. This lack of control led to inconsistency of the strength values and increased the difficulty of producing castings to a predetermined specification.

Among the many investigators was Meehan who, in 1924, experimented in the manufacture of grey cast iron of superior strength and physical properties, by the use of an agent to promote graphitisation from many nuclei. This type of iron was developed by Smalley and others, and as a result of many years' concentrated research it represents the greatest advance that has ever been made in the metallurgy of cast iron.

The particular type of high duty iron developed from the original idea of Meehan is known as Meehanite Metal. It can be controlled to meet definite service requirements and possesses physical properties superior to cast iron or semi-steel. The methods developed permit of absolute control, removing uncertainties and resulting in a material which can be relied upon, at all times, to give the service properties called for. The name applied to a group of high duty irons, comprising nearly thirty, each of which is manufactured, under a strict system of control, to possess certain properties and characteristics, which will make it suitable, in the highest degree, for meeting some specific service requirement.

No one type of iron is suitable for each and every service condition. In general, service requirements place a casting in one of the following categories, which indicate the service and properties required for that service.

General Engineering.—Strength, toughness, resistance to shock, damping capacity, machineability. Pressure tightness.

Heat Resistance.—Retention of strength under continuous or intermittent high temperatures. Resistance to scaling, or distortion. Non-growing.

Wear Resistance.—Resistance to abrasion and erosion, impact, rolling or sliding friction. Freedom from galling or seizing under severe conditions.

Corrosion Resistance.—Ability to resist chemical attack, by acids or alkaline liquids or vapours.

The process developed permits control of the metal to definite specification to meet service requirements. The metal in each ladle may be processed to meet a given set of conditions of mass influence, as it affects strength, hardness and machineability, so that uniform density and strength properties in castings of varying sections are assured.

Uniformity

From an engineering point of view the influence of mass on the strength of the material employed is especially important. The engineer wishes to know the extent to which he can rely upon the load carrying capacity of the different sections in a casting. The uniformity of Meehanite Metal in comparison with semi-steel cast iron poured into 12-in. cubes is shown in Fig. 1, which

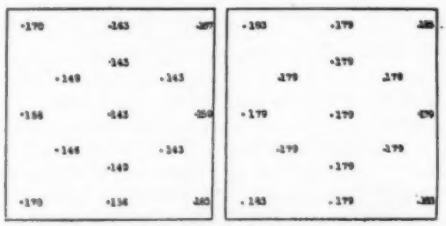

Fig. 1A.—Semi-steel cast iron, 12-in. blocks.

Fig. 1B.—Meehanite Metal, 12-in. block.

gives the hardness values obtained on their centre sections. The considerable fall in the hardness from the outside to the centre of the grey iron cube will be noted; on the other hand, the hardness of the Meehanite casting, apart from the corners, shows remarkable uniformity. The structures of the same cast iron and Meehanite Metal, in 2-in. as well as 12-in. cubes, are shown in Figs. 2 and 3, which support the greater uniformity indicated by the hardness test. A further comparison

TABLE I.—COMPARISON OF MASS EFFECT.

Dia. of bar from which test bar was cut, in inches.	Tensile Strength, tons/sq. in.	
	Grey Iron	Meehanite
0·75	12·3	—
1·25	11·6	23·95
2·0	8·25	24·25
3·0	6·8	23·7
4·0	—	22·7
6·0	—	21·2

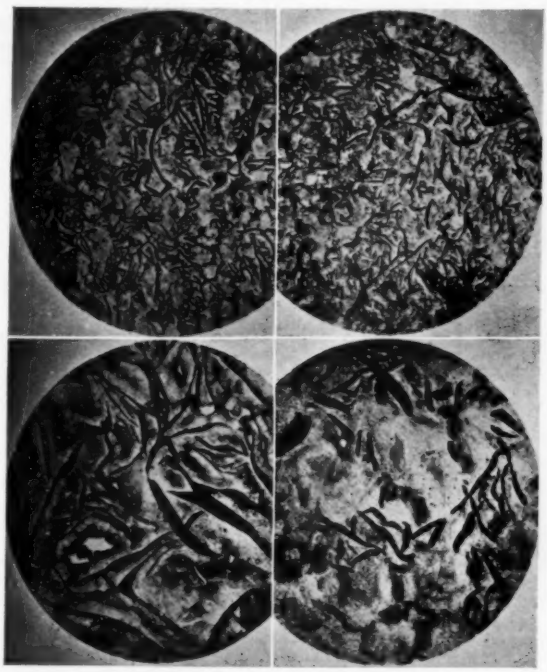

Fig. 2.—Semi-steel cast iron, × 33. Upper—from 2-in. section. Lower—from 12-in.section.

Fig. 3.—Meehanite Metal × 33. Upper—from 2-in. section. Lower—from 12-in. section.

of the effect of mass on the ultimate strength is given in Table I, which gives average figures of a considerable number of tests from bars supplied by several foundries.

That almost the full strength is maintained throughout a 3-in. section and 90% in a 6-in. section is an outstanding feature of the process. The method developed assures control of a random form of graphite distribution in predetermined quantity suitably dispersed in a matrix wholly pearlitic or sorbitic. It provides a means of measuring the constitution of the molten metal in relation to the section of the castings, and assists the establishment of a ratio between the constitution of the metal before and after processing that will ensure uniform density and solidity in all sections as well as predetermined engineering properties.

General Engineering Types

In the engineering range is a group of types which provide materials having tensile strengths varying from 15.30 tons/sq. in. in the "as cast" condition and higher strengths by special treatment. Selection of the right material to meet specifications for service conditions has been simplified, in the case of Meehanite Metal, by the use of five main processes in manufacture for general engineering applications. Each of these processes are designated by symbols, GA, GB, GC, GD, and GE, the tensile strength of which range from a minimum of 24 tons/sq. in. in GA to a minimum of 14 tons/sq. in. in GE.

In order to maintain standard strength, hardness and free machinability, there is a minimum thickness of section at which each process should be cast. The GE and GD types may be poured into sections below $\frac{3}{8}$ in. and still retain greyness and free machinability. There is, however, a border line change between grey and white material, which gives rise to an improved structure that increases physical properties. This change is most pronounced in GD and GE, which are those best suited for thin sections. Type GA is approximately 24 tons/sq. in. when poured in 1-in. sections and may show a small increase if poured into thinner sections, but in sections under $\frac{1}{2}$ in. the strength may fall and the metal present machining difficulties. Type GC in 1-in. section, which gives 20 tons/sq. in. in tensile, will show an increase in strength to 23 tons as the section is reduced to $\frac{3}{8}$ in. Thus GC in $\frac{3}{8}$-in section compares with GA in $1\frac{1}{4}$ in. or with type GB in 1-in. section so far as strength is concerned. It is important, therefore, when specifying physical properties in light castings that are to have easy machining qualities, the effect of sectional dimensions must be kept in mind. Figs. 4 and 5.

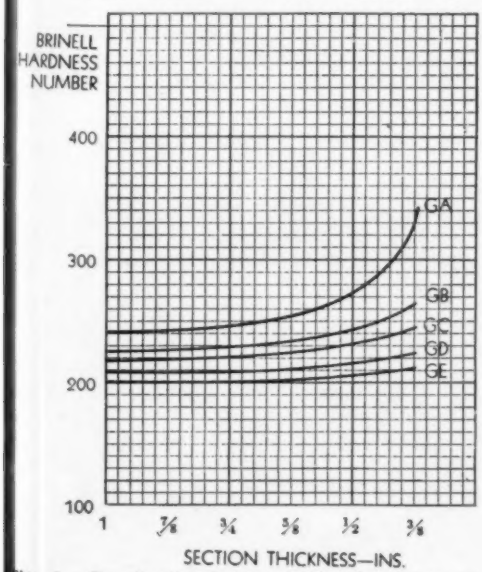

Fig. 4.—Graph showing increasing hardness of metal with decreasing section thickness.

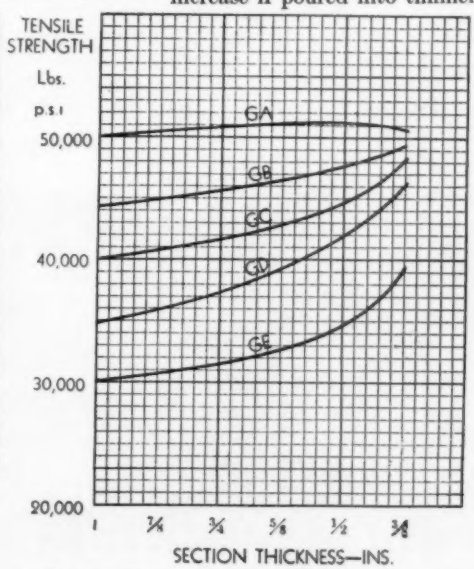

Fig. 5.—Graph showing change in tensile strength with decreasing section thickness.

The old concept of cast iron as a brittle material, which showed no straight line relationship between stress and strain, does not hold good with this material. This is clearly shown in the stress strain modulus curve of a GB type, obtained at atmospheric temperature, Fig. 6. While the curve Fig. 7, which represents the result obtained on the same GB type at a temperature of 400 °C., shows that even at high temperature the material possesses elastic properties and a very definite range of plasticity. The straight line relationship is not confined to tensile testing, but is found to be equally evident in compression and torsion.

Fatigue Properties

Fatigue or endurance is a fundamental property that must be considered with the tensile characteristics in designing, and results of tests made on ordinary cast iron, alloy cast iron, and high-test cast iron made by the Meehanite process are noteworthy. The specimens for the grey iron, alloy cast iron and type GB material we cut from 6-in. blocks for the tests. The results are compared with other materials in Table II. The favourable showing of the GA and GB materials will be noted. Two reasons are given for this : (1) The property of crackless plasticity of the material which permits of an occasional overstress without the development of a crack that in later service will spread to fracture. (2) a high damping capacity for vibration which prevents resonance stresses from building up to critical proportions. In other words, the internal friction of the metal converts the energy of vibration into heat and disperses it.

Damping does not foretell impending fatigue failure, nor does it tend to disappear under prolonged cyclic stressing. On the contrary, it is capable of dissipating an unlimited amount of energy in heat without damage to the material. Ultimate damping, that is, the steady value attained after some millions of cycles, is often greater than initial damping.

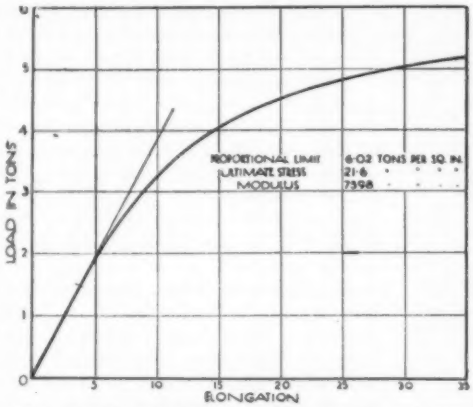

Fig. 6.—Stress strain modulus curve of a GB type Meehanite at atmospheric temperature. 1 Unit —0·005 cm. Gauge length 2 ins.

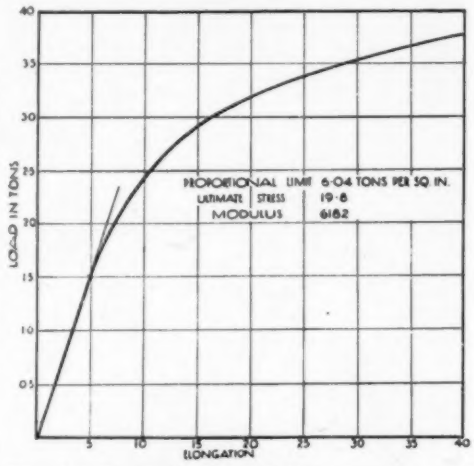

Fig. 7.—Stress strain modulus curve of a GB type Meehanite at a temperature of 400° C. 1 Unit—0·005 cm. Gauge length 2 ins.

The importance of having available a material which can absorb vibration stresses rapidly is appreciated by the engineer. This is one reason why cast iron has been extensively used for parts where vibration has to be reduced to a minimum. Unfortunately, in ordinary cast iron, the damping capacity falls at the tensile strength. This also applies to Meehanite higher processes ; but as a result of research a method has been evolved for a special processing of the high strength metal, whereby the damping capacity can be increased to nearly the same as that of soft low strength cast iron.

Impact Test

Recently a British Standard impact test has been adopted for cast iron, in which a modified Izod test on an unnotched test piece, machined to 0·798 in. diameter, is used, in the standard 102 ft-.lb. machine fitted with a special vice. This test is purely empirical, but does appear to show comparative results between materials, of the cast iron type, available in engineering industry. Average results from many tests on Meehanites by this method are shown in Table III.

TABLE III.—IZOD IMPACT TESTS ON 0·798 IN. DIAMETER UNNOTCHED TEST PIECES.

Type	Impact Ft.-lb.
GA	25–35
GB	15–23
GC	12–20
GD	9–15
GE	6–12

Toughness

The property known as toughness is something which is difficult to define, but is commonly understood to be the opposite to brittleness. In the majority of cases there is no definite line of demarcation between toughness and brittleness. Cast iron has been described as a brittle material because it breaks without showing appreciable plastic deformation, but this is not so in the case of Meehanite high duty irons. A reference to the modulus curves in Figs. 6, and 7 will convince that there is a very definite plastic range between the yield point to the point of fracture.

Full appreciation of high duty cast iron, however, has,

TABLE II.—SOME FATIGUE TEST COMPARISONS.

Material	Endurance Limit lbs. sq. in.	Endurance Limit % tensile.
Malleable cast iron	24,000	53
Steel casting (0·30C)	30,000	40
Steel forging (0·37C)	30,000	44
Welded steel structure	12,000	30
Ordinary cast iron	9,000–12,000	43
Meehanite GA, as cast	21,000	40
Meehanite GA, heat treated	28,000	—
Meehanite GB, as cast	19,200	47
Alloy cast iron	10,500	34
Grey cast iron (semi-steel)	10,064	42

Fig. 8.—Cast crankshaft for marine diesel engine in Meehanite.

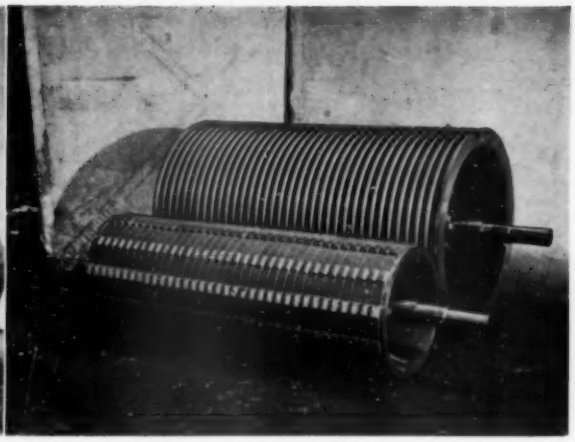

Fig. 9.—Ore screening rolls.

in many cases, been delayed on account of a somewhat mistaken view of the value of ductility in engineering. It is important to differentiate between the generally recognised physical properties and those actually required to meet service demands. The main interest in engineering is that the material shall be able to resist, without deformation or fracture, the stresses to which it will be submitted in service. The elongation value is not by itself a criterion, in design, of serviceable material; it is only incidental to the essential property—i.e., the effective strength to the limit of elastic deformation. An interesting example of non-ductile material standing up to severe service conditions, where high tensile strength, fatigue and torsional properties in combination together with density and solidity are necessary, is found in the cast crankshafts for Diesel engines. Here all previously held ideas are negatived, and a casting, in a metal giving practically no elongation, proves not only satisfactory for the application, but is in some ways superior to a forged steel crankshaft.

Fig. 8 shows a cast crankshaft for a five-cylinder engine of 325 h.p. at 440 r.p.m. The cylinders are 12½-in. bore, 16-in. stroke, The shaft is 11 ft. 6 in. long and weighs 30 cwt. Meehanite crankshafts have been cast in many sizes and to many designs, with very definite advantages, due to the absence of notch effects, with high damping capacity as well as a shorter machining time, with lower costs of production.

TABLE IV.—CREEP-RATE DATA ON ENGINEERING MEEHANITES AT 750° F.

Type	Stress lbs./sq. in.	Creep-Rate at in./in./hr.	2,000 hrs. per cent. 10,000 hr.	Strain or Total Elongation at 2,000 hr. %
GA	5,000	$3{\cdot}0 \times 10^{-8}$	0·03	0·015
GA	10,000	$7{\cdot}5 \times 10^{-8}$	0·075	0·045
GM	5,000	$1{\cdot}5 \times 10^{-8}$	0·015	0·010
GM	10,000	$2{\cdot}5 \times 10^{-8}$	0·023	0·015
SC2	5,000	$1{\cdot}7 \times 10^{-8}$	0·017	0·010
SC2	10,000	$5{\cdot}0 \times 10^{-8}$	0·050	0·022

Creep Properties

Creep properties of materials have been extensively investigated in order that the engineering designer may obtain specific information about their behaviour at various temperatures under defined stress conditions.

The desired sensitivity of creep tests or the order of magnitude of the creep data depends upon the service application. In some cases up to 800° F. the service may require maintenance of dimensional stability where data on stress-strain relationships involving very low strain rates are essential. At higher temperatures larger strain rates may be permissible. In some instances it is required to know the stress-temperature characteristics

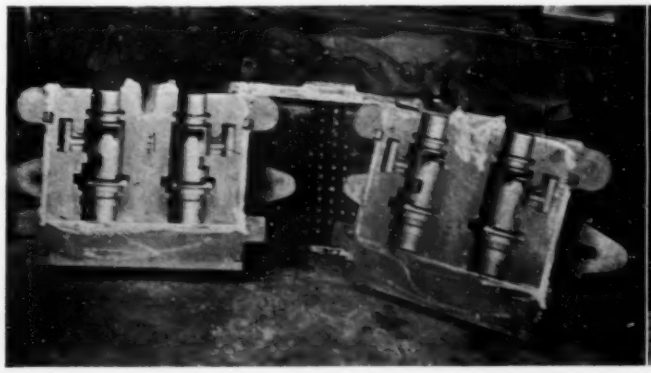

Fig. 10.—Dies for die-casting cast-iron motor-car housings.

Fig. 11.—A pair of helical gears in Meehanite.

TABLE V.—THE APPROXIMATE CREEP STRENGTH VALUES IN CONJUNCTION WITH GROWTH AND SCALE RESISTANCE OF THE HEAT RESISTING MEEHANITE TYPES HD, HC AND HR.

Temperature	Approximate Creep Strength (lb. p.s.i.)			Maximum Growth per inch per year			Maximum Surface Metal Loss per year		
	Meehanite Types			Meehanite Types			Meehanite Types		
	HD	HC	HR	HD	HC	HR	HD	HC	HR
800° F.	3,800	—	—	Nil	—	—	—	—	—
900° F.	3,800	—	—	Nil	—	—	—	—	—
1,000° F.	3,200	6,000	—	Nil	Nil	—	0·003 in.	—	—
1,100° F.	2,300	3,750	4,000	0·002 in.	Nil	—	0·005 in.	—	—
1,150° F.	1,600	3,000	3,150	0·005 in.	Nil	—	0·008 in.	0·003 in.	0·003 in.
1,200° F.	—	2,250	2,500	—	0·001 in.	0·001 in.	—	0·005 in.	0·005 in.
1,300° F.	—	1,600	1,800	—	0·002 in.	0·002 in.	—	0·008 in.	0·008 in.
1,400° F.	—	800	900	—	0·005 in.	0·005 in.	—	0·010 in.	0·010 in.
1,450° F.	—	—	300	—	—	0·010 in.	—	—	0·020 in.

over some given period during which freedom from failure by fracture can be guaranteed.

In Table IV the results of creep tests for two engineering types and a special heat-resisting type of Meehanite are given. The tests were made on pieces 0·358 in. diameter over gauge length 2in. Further creep characteristics are given in Table V which are results of tests on some special heat resisting types of Meehanite.

On account of its ability to maintain strength characteristics, and dimensional form at elevated temperatures, Meehanite is largely used in internal combustion engine construction, particularly for such parts as cylinder heads, pistons, liners and fuel valves.

Some Other Properties

The process is successfully employed in the making of castings for wear-resisting applications. Wear, however, is essentially a surface phenomenon, and involves many properties, such as hardness, fatigue, impact, friction, corrosion, structure and lubrication, some of which are not thoroughly understood. Each wear problem must be separately considered on its merits and according to the conditions of service before a selection can be made for any application. There are eight types of wear-resisting Meehanites, each designed to meet a specific type of service. They have many applications for such purposes as ball mill liners, cement and stone crushers, rollers and mining machinery. They have, in many cases, replaced manganese steel for beater plates, pulverising hammers, ball mill liners and segments, and ash ejectors. A typical example is shown in Fig. 9 which shows a pair of ore screening rolls.

Cast iron has long been favoured for casting dies, but usually where the number of pieces required is small. In recent years, however, improved foundry technique and the controlled process employed has enabled the designer to work to a file finish on a considerable number of dies. Such dies are cast true to pattern and so smooth that they can be put to work with little or no machining. The wearing properties of the material are exceptional, the hardness in the cast state being from 200 to 280 Brinell. The metal works up to a very fine polish after the first few hundred stampings and does not gall, scratch or load to the extent of tool steel. In addition to dies for stampings considerable success has been achieved in using the process for casting dies. An example of such a die is shown in Fig. 10 ; it is used for die casting a motor-car housing in cast iron.

As is well known cast iron still accounts for a very large proportion of the gears made. Metallurgical research into the properties of cast iron has resulted in a much clearer knowledge of the factors involved in the production of a perfect gear material. Work carried out at the Meehanite Research Institute emphasised that the structural make-up of the material is the all-important factor.

The principal properties of cast iron-type of material of direct major importance to designers of gears are : High strength in tension and compression, wear resistance, low co-efficient of friction, stability and freedom from distortion, high damping capacity and good machinability. A considerable research has been carried out during recent years to determine the surface and bending stress factors of Meehanite gears, by David Brown and Sons (Hudds.), Ltd. Table VI shows the characteristics of such gears in comparison with cast iron, bronze and cast steel. A pair of helical gears in Meehanite are shown in Fig. 11.

TABLE VI.—BASIC SURFACE AND BENDING STRESS FACTORS FOR SPUR AND HELICAL GEARS (D.B.S. SYSTEM).

Type of Material*	Minimum Tensile Strength, Tons/sq. in.	Minimum Brinell Hardness Number	Surface Stress Factor (Sc.)	Bending Stress Factor (Sb). Lb./sq. in.
Malleable castings	20	140	850	11,000
Cast iron	12	165	1,000	5,800
Cast iron	16	210	1,350	7,600
Cast iron (alloyed)	22	220	1,450	10,400
Phosphor bronze (sand cast)	12	69	700	7,000
Phosphor bronze (centrifugally cast)	17	90	1,000	10,000
Cast steel (carbon 0·35/0·45%)	35	125	1,400	19,000
Meehanite "GC"	18·5	190	1,400	14,000
Meehanite "GA"	23	210	1,450	14,500
Meehanite "GM"	27	230	1,600	14,000
Meehanite "GM" (heat treated)	28†	300	2,400	16,000
Meehanite "GM" (heat treated)	28†	425	2,400	17,500

* Refer., B.S.S. 436/1940. † Tensile as cast.

System of Control

The Meehanite process is operated under a number of patented inventions. Prominent among them are patents related to accurate regulation of combustion conditions throughout the whole period of melting in the cupola. The constitution of the molten metal in relation to the size and dimensions of the castings or of the physical properties required is measureable. The application of statistical principles to test data places the process on a quantitative basis. Casting reliability is measured not by the highest property value the foundry can supply in one particular type of casting, but by the consistency with which the values are maintained to standard. This is accomplished in this process by the application of statistical quality control systems and the known properties of the frequency distribution curve are employed to determine the limits within which all test values should lie.

It is emphasised that, by specifying the exact requirements in regard to strength or other properties, and giving details of the conditions of service the casting will be required to meet, the foundry can supply the material experience has shown to be best suited for the purpose.

The Fracture of Solids

III—Random Fracture of Solids and Natural Frequency Distributions

By R. L. Brown

British Coal Utilisation Research Association

The further paper before the conference on The Fracture of Solids organised by the British Rheologists Club was that given by Mr. R. L. Brown, who discussed the fracture of coal in its relation to size distribution of fragmented pieces. He showed that when the size distribution of broken coal deviates from the natural distribution, further rough handling of a consignment tends to promote natural size distribution. In the case of coal, millions of particles are involved and individual test specimens are unsuitable: strength measurements are made by the shatter test, in which the coal is dropped several feet on to a steel plate, and the strength calculated from the resulting degradation

IN the past, engineers confronted with the task of designing breaking and handling machinery, received but little help from scientists. Recently the physical mechanism and mathematical expression of fracture have received greater attention. It is of particular interest to note that frequency distributions other than the Gaussian distribution and yet characteristic of natural phenomena are emerging from these investigations.

The fracture of solids such as ores, coal, fibres and many other substances, is essentially determined by flaws in the material. Great attention has been given to the weakest link hypothesis, first formulated by Peirce[1] and recently placed in its statistical context by Epstein.[2] This hypothesis that the strength of a chain is that of its weakest link is relevant to fibres,[1] broken under a steadily increasing load and can be used to deduce the effect of the length of the fibre. Daniels[3] has discussed the breakage of fibres arranged in parallel, with the load distributed between them. Combinations of Peirce's and Daniel's analyses appear to be needed for three-dimensional solids, but useful results have been obtained by Weibull and Frenkel & Kontorova[5] who assumed that the number of flaws n is the most significant factor and neglected their volume distribution.

Epstein[2] demonstrates that all these theories have a close analogue in the statistical theory of the distribution of extreme values in samples of size n drawn from various populations. He assumes various population frequency distributions (rectangular, Cauchy, Laplace, Gauss, etc.), for the strength of the flaws and evaluates the relationship between strength and volume V of specimens. A relationship between strength and log V is found in the more interesting cases discussed by Epstein, as earlier workers had shown. There are experimental data in support of such a relationship.

The above theories can refer only to fracture of solids under slowly applied loads. It often happens in industry that large loads are applied suddenly. Brown[6] has proposed the hypothesis that in this case the strength is determined by the extent (area) of the flaws in the material, it being supposed that simultaneous (or nearly so) failure occurs at many points in the solid. This supposition is necessary to account for the fragmentation of many solids, under impact, into numerous pieces having different sizes. Brown also derives a strength/volume relationship and reports confirmatory, although admittedly inadequate, evidence for coal.

The size-frequency distribution of the fragments produced by a single impact is an exponential distribution[7] and as Bennett[8] has shown, such a distribution is accounted for by assuming that flaws are randomly distributed throughout the volume of the lump, and that fracture at each of them is equally probable, as would be the case when the impact forces are large. Repeated breakage of every piece in an assembly leads them to a sum of exponential distributions cut off at upper size limits. This sum has been shown[9] to approximate well to an expression found experimentally by Rosin and Rammler[10] and since applied to many substances by other workers.[11] The mathematical implications of this approximation have not been investigated.

Epstein[12] has adopted another model of the breakage process and has shown that the powerful central limit theorem in statistics leads to the logarithmico-normal distribution for particle sizes. In this model the notion of repeated breakage is retained, it being assumed that the probability of breakage of a particle is π_i ($0 < \pi_i < 1$) in the i^{th} step, π_i being constant and independent of the size of the particle and of the presence of other particles. When it is assumed further that the distribution of particles is independent (up to an upper limit) of the dimension of the piece broken,* the size distribution after a number of breakage steps can be calculated, and it is found that the distribution tends asymptotically to the logarithmico-normal law.

There are thus two models for which strength/volume relationships and size-distribution laws can be derived. The need is now for experimental data with which to test the theoretical analyses and to refine the models. At present, theory is far in advance of practical applications. This striking reversal in knowledge of the random fracture of solids has taken place in the past few years.

Although both of these models have been proposed for the same physical process of destruction and although they appear to be algebraically related, they are fundamentally different. The logarithmico-normal law, as Gaddum[13] had recently re-emphasised, is simply a variant of the Gaussian law, according to which the variate actually measured is related algebraically to the variate x which follows the law.

$$df = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(x-\bar{x})^2/2\sigma^2} dx \quad \ldots\ldots\ldots (1)$$

* This second assumption has been verified experimentally for coal breakage. It is possible that Brown's[6] derivation of the Rosin-Rammler law could be generalised in a similar manner.

The sum of two variates separately satisfying equation (1) also follows the Gaussian law. The Gaussian law is found to apply to many biological phenomena and corresponds to the Maxwellian law in physics. It may be derived from the postulate that there are numerous small and independent influences causing deviations from a mean value. Similarly, as Brown has shown, the Rosin-Rammler law is an approximate expression for a generalisation of the compound interest law, so that it is also additive and may be regarded as a variant of the law :

$$df = A.f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The expression :

$$df = A\, x^{a}\, e^{-\,b\,(x\,-\,c)^{n}}\, dx \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

reduces to the Gaussian law when $a = 0$, $n = 2$; to the Rosin-Rammler law when $a = (n - 1)$, $c = 0$; and to equation (2) when $a = 0$, $c = 0$, $n = 1$.

It would seem, therefore, that there is an algebraic transformation whereby data satisfying the Rosin-Rammler law (or equation (2)) may be cast into normal form.

It is important to note that the use of such a transformation is liable to obscure the underlying physical processes. The Gaussian law is fundamentally a *conservation* law. Only with Epstein's assumption of a very large number of breakage steps is this law found to apply to broken solids. The Rosin-Rammler law is fundamentally a law of *destruction*, where after one breakage step, the parameter n is unity and in successive steps decreases steadily. Thus the difference between the two laws is essentially one of *scale*. A destructive process in which the product of destruction is on the same scale as the starting material, is a variant of equation (2). But if the process continues far enough, so that the product is on the next smaller scale than the original material, it is the conservation law that applies.

This rather abstract formulation of the issue may be illustrated by considering the breakage of a 6-in. lump of coal. Even when crushed and ground to 1/100 in. and smaller sizes, the size distribution is that of the Rosin-Rammler law. But this law cannot apply right down to sizes of (say) 5 microns and less, for then the surface area (since $n < 1$) would be infinite. Thus the ultrafine sizes depart from the destructive law. There is, of course, a change of scale in the forces needed to disrupt ultra-fine particles as compared with those needed to break larger, cracked particles. In fact, the end-point of mechanical size reduction of coal is an assembly of micelles or small aggregates of micelles, and these are known[14] to be the outcome of a growth process which conserves their sizes.

These considerations suggest that the fracture of cracked brittle solids leads to an assembly of pieces having for weight-size distribution :

$$\left.\begin{aligned} df &= Ax^{n-1}\, e^{-(x/\bar{x})^{n}}\, dx \quad x > x_{o} \\ df &= Ax^{n-1}\, e^{-(u/x)}\, dx \quad x < x_{o} \end{aligned}\right\} u \ll x_{o} \ll \bar{x} \quad (4)$$

where x_o is the size (linear dimension) at which there is a change of scale df is the weight of material between sizes x and $x + dx$. The expression for $x > x_o$ is the Rosin-Rammler law ; that for $x < x_o$ is the law derived by Griffith,[15] u being a scale parameter. There is at present no experimental evidence to support equation (4) but use of the electron microscope can be expected to provide an experimental test in due course.

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Staff Changes and Appointments

SIR BEN LOCKSPEISER is to succeed Sir Edward Appleton as Secretary to the Privy Council for Scientific and Industrial Research. During the war Sir Ben, who will take up his appointment on May 1, 1949, took a leading part in the direction of aeronautical research. At the end of 1946 he was appointed to the newly created post of Chief Scientist to the Supply Ministry.

DR. C. SYKES has been nominated by the Council of the Iron and Steel Institute as its representative on the General Board of the National Physical Laboratory, for a five-year period from January 1, 1949. He succeeds Professor J. H. Andrew, Dean of the Faculty of Metallurgy at Sheffield University.

MR. G. C. H. MATTHEY, after 45 years' service with Messrs. Johnson, Matthey and Co., Ltd., is retiring from the Executive Committee of Directors, but will continue as a member of the General Board of Directors.

DR. F. C. LEA, Emeritus Professor, Sheffield University, and a Director of Edgar Allen & Company, Limited, has been made an Honorary Member of the Institution of Mechanical Engineers.

MR. G. W. ALLOTT, technical adviser to the managing director, Newton Chambers & Co., Ltd., has retired at the age of 65. He is a former president of the Ironfounders' National Federation, East and West Ridings Branch, and is a member of the main committee of the British Chemical Plant Manufacturers' Association.

MR. H. E. L. FREYTAG, after 15 years in the Information Department of the British Non-Ferrous Metals Research Association, has taken up the post of Information Officer to the British Boot, Shoe and Allied Trades Association, Satra House, Rockingham Road, Kettering, Northants.

DR. F. MEYER, Works Manager of the South African Iron and Steel Corporation (Iscor), has been appointed Chairman in succession to the late Dr. H. J. van der Bijl.

MR. H. A. CHAMBERS has been appointed General Manager of the Rockwell Machine Tool Co., Ltd. For 21 years he was attached to the London office of Associated British Machine Tool Makers, Ltd. From 1940 to 1945 he was lent to the Ministry of Supply, occupying the position of Assistant Controller in charge of the allocation of machine tools.

Mr. O. W. Humphreys, B.Sc., F.Inst.P., A.M.I.E.E., has been appointed Manager of the General Electric Company's Research Laboratories at Wembley, Middlesex. Mr. Humphreys joined the staff of the Laboratories in 1925, and was appointed to its Leading Scientific Staff in 1927, originally in charge of the Heat Group. The scope of the activities of the Laboratories, which now employ a staff of over 1,300, has increased greatly. In the directing and co-ordination of these diverse activities Mr. Humphreys will be advised by a small Advisory Scientific Panel of his colleagues. Dr. B. P. Dudding, who joined the staff as a founder member with Sir Clifford Paterson in 1919, has been appointed Vice-Chairman of this Panel.

Mr. H. L. Satchell, M.B.E., Manager of the B.T.H. Rugby Works, and its associated Factories at Peterborough, Leicester (Blackbird Road) and Nelson (Lancs.) has been appointed a Director of The British Thomson-Houston Co., Ltd. In February, 1920, he was accepted for apprenticeship with B.T.H. and was awarded a B.T.H. Fellowship in November, 1921. He proceeded to the General Electric Co., U.S.A., for one year, and on his return to Rugby in December, 1922, became Technical Assistant to the Head of the Winding Department. In May, 1929, he was appointed Planning Engineer; in June, 1940, Assistant Manager, and in February, 1945, Manager, Rugby Works. He is a Founder Member of the British Works Management Association, which is now absorbed in the Institution of Works Managers.

Mr. C. Hulme has been appointed Assistant Works Manager of the Port Talbot and Margam Works of the Steel Company of Wales.

Mr. Hulme has been, since 1945, Blast Furnace Manager at the North Works of the Appleby Frodingham Blast Furnace Department. Having taken an honours degree in Civil and Mechanical Engineering at the University of London, he spent periods of training with Alfred Herbert Limited, of Coventry, and in the Fuel Efficiency Department of the Appleby Frodingham Steel Company at Scunthorpe. A further two years were spent in training with the United Steel Companies in their Appleby-Frodingham, Workington, Steel, Peech and Tozer, Samuel Fox and Rotherdale branches.

Mr. J. Calderwood, M.Sc., M.I.N.A., M.I.Mar.E., A.F.R.Ae.S., has resigned his appointment as Manager of the Diesel and Marine Department of Sulzer Bros. (London), Ltd., to join Associated British Oil Engines, Ltd., as Technical Director.

Mr. W. F. Hammond has been appointed a Director and Chairman of the Blænavon Company, Limited. Mr. F. A. Ward has been appointed a Director. They replace Major C. D. Morrison and Mr. E. W. Thornton, who have resigned from the Board.

Mr. M. C. Lloyd, Director and Joint General Manager of Howell & Co., Ltd., Sheffield Tube Works, has been appointed Director and General Manager of the Weldless Steel Tube Co., Ltd., and of Tube Rolling Mills, Ltd.

Mr. W. J. Thomas, Director and General Production Manager of The British Aluminium Company, Ltd., was appointed Assistant Managing Director of that Company as from 1st January, 1949.

Mr. A. H. Plews has succeeded the late Mr. H. E. P. Beard as a Director of the Neepsend Steel and Tool Company, Limited.

Mr. W. K. B. Marshall, B.Eng., A.I.M., has accepted the appointment of Assistant Director of Research of the British Welding Research Association. Mr. Marshall was for some years Works Metallurgist at the Milton Works of the British Aluminium Co., and for the past eight years has been the Chief Metallurgist and later Chief Development Engineer to the A.P.V. Co., Ltd., Wandsworth.

A graduate of Liverpool University, Mr. Marshall is well known for his work on light alloy and stainless steel welding. In his new position he will pay particular attention to the non-ferrous welding investigations of the Association's programme. He is expected to take up his duties on March 1st, 1949.

Mr. A. Chamberlain has been elected a Director of Tube Investments, Ltd. He is Managing Director of the Tube Investments subsidiary, The Hercules Cycle & Motor Company, Ltd.

Mr. A. Keats, Managing Director of Fisher & Ludlow, Ltd., has been appointed Chairman.

Mr. E. M. Cleland, of Bairds and Scottish Steel, Ltd., has been appointed Chairman of the Scottish Lime and Limestone Association for the year 1949.

Dr. S. G. Hooker, O.B.E., B.Sc., D.I.C., Ph.D., A.F.R.Ae.S., has been appointed to the staff of the Bristol Aeroplane Company, Ltd., as assistant to Mr. F. M. Owner, Chief Engineer, Aero Engine Division. Dr. Hooker is, of course, especially known for his work on gas turbine development.

Obituary

We regret to record the death of Mr. J. H. G. Monypenny at the age of 63. Educated at Sheffield Royal Grammar School, later King Edward VII School, and the Technical Department of the University College, later the Department of Applied Science of Sheffield University, he obtained the Associateship in Metallurgy and the Mappin Medal in 1904.

In October, 1904, he joined Messrs. Brown, Bayley's Steel Works, Ltd., in whose employ he spent the whole of his working life. He started the Research Laboratory and was head of that department until 1930, when he became Technical Representative, which position he occupied until 1945, when, owing to ill health, he retired from active service with the firm.

Mr. Monypenny, who was also a Fellow of the Institute of Physics and a Fellow of the Institution of Metallurgists, was the author of numerous technical articles, many of which were published in this journal, but is no doubt best known as the author of "Stainless Iron and Steel." During his career he served on several Technical Committees and was a Member of Council of the British Chemical Plant Manufacturers' Association for over 20 years and the Chairman of that Association from 1935 to 1938.

The Mond Nickel Co., Ltd.

The Mond Nickel Co., Ltd. announce that on March 28th, 1949, they are moving their head offices from Grosvenor House, Park Lane, to Sunderland House, Curzon Street. After that date the address of the head offices of The Mond Nickel Co., Ltd., Henry Wiggin & Co., Ltd., and Mond Nickel (Retirement System) Trustees Ltd., will be Sunderland House, Curzon Street, London, W.1. Telephone: GROsvenor 4131, Telegrams: Nictatio, Telex, London.

MICROANALYSIS
CHEMICAL AND PHYSICAL METHODS
APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

Group Separations in Inorganic Qualitative Analysis

Part II—Sulphide and Potential Sulphide Ion Reagents

By Francis R. M. McDonnell and Cecil L. Wilson

Microchemistry Laboratory, Chemistry Department, The Queen's University of Belfast.

In the first part of this review, the schemes described depended on the use of gaseous sulphuretted hydrogen as the reagent. It is also possible to supply sulphide ion either by sulphuretted hydrogen in solution, by the use of a non-volatile sulphide, or by employing other sulphur compounds which decompose readily with the liberation of sulphide ion. A number of schemes of analysis employ one or other of these approaches, and are described.*

IN the sulphide schemes, the classical reagent, gaseous hydrogen sulphide (or hydrogen sulphide in aqueous solution), suffers from several defects. The gas is comparatively insoluble in aqueous or acid solution, leading to a small concentration of the sulphide ion and slow precipitation, and when improperly used it is obnoxious, and, indeed, extremely dangerous.

Of the reagents which have been introduced to combat these defects, the use of the gas in a more suitable solvent seems, at first sight, to have possibilities, and has recommended itself to various workers. The concentration of the sulphide ion is thus increased, though much of the gas is liable to escape into the atmosphere.

Solutions of Sulphuretted Hydrogen

According to Pérronnet and Remy[1] dry hydrogen sulphide dissolves in acetone to an extent of 22·4 g./l. The hydrogen sulphide is not readily lost by exposure to the atmosphere, and the solution is stable for 6-12 months. After this time an insoluble product, possibly consisting of thioketones, is formed. The solution can be used instead of an aqueous one in qualitative analysis, and because of the high concentration of sulphuretted hydrogen (solubility of H_2S in water has been variously reported as 3·7 to 4·1 g./l. at 20° C.) precipitation is claimed to be much more effective than with an aqueous solution, the results being much more comparable with those obtained by use of the gaseous reagent.

Geddis[2] advocates the use of a resin, Amberlite IR–4, saturated with gaseous hydrogen sulphide as a precipitant for the Group II cations. Although this reagent is undoubtedly not a true solution of sulphuretted hydrogen, its use is in the first instance dependent on a supply of the gas at a high concentration, and so the reagent may be considered to be analogous to the acetone solution just mentioned. The exhausted resin is practically undissolved in any of the normal processes applied in the separation of Group II. It is claimed that, with the possible exception of aluminium, the cations of Group III are not co-precipitated to any appreciable extent. Further, the resin has the power of absorbing the phosphate ion, so that, using this reagent, it is unnecessary to modify the Group III procedure when that radicle is present.

Use of a resin in this way is reminiscent of certain methods of preparing hydrogen sulphide. Prothiero,[3] in 1903, describes the preparation of the gas by heating a mixture of vaseline and sulphur, and later Henwood and his co-workers[4] advocate sulphur and paraffin wax for the same purpose, while Gfeller and Schaefer[5] state that a hydrocarbon and sulphur mixed with ignited asbestos can be used for preparing the gas.

Other Sulphides

Phosphorus pentasulphide has been advocated by Purgotti[6] as a precipitant for Group II.[7] The solution to be analysed is shaken with the reagent at 50–60° C. until a small portion gives no precipitate with hydrogen sulphide. This is rather an anomalous procedure, since the reagent was introduced to obviate the use of gas.

Several schemes have been proposed which dispense with the precipitation of sulphides in acid solution, and rely on the insolubility of certain sulphides in alkaline solution, the precipitant being ammonium or the alkali

* *Metallurgia*, 1948, **38**, 177.
1 Pérronnet and Remy, *J. pharm. chim.*, 1939, **30**, 170.
2 Geddis, *J. Chem. Educ.*, 1942, **19**, 327.
3 Prothiero, *Chem. Zentr.*, 1903, i, 492.
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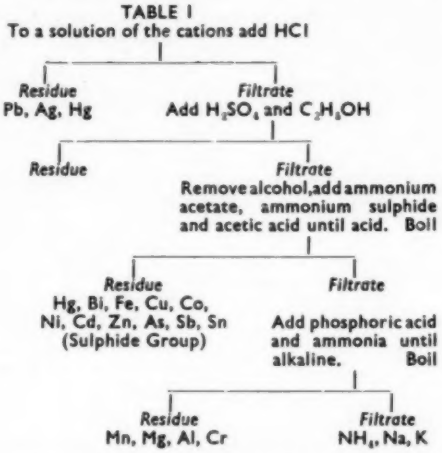
7 See also Part I, *Metallurgia*, June and July, 1948, **38**, 177.

sulphides. Cornog[8] states that alkali metal sulphides in alkaline solution will separate a considerable number of cations completely and cleanly, the exceptions being cobalt and nickel sulphides, which tend to form colloidal solutions, these being difficult to filter. This difficulty he overcame by the use of ammonium sulphide in solution buffered with acetic acid-acetate. The principle was incorporated in a scheme of analysis by Cornog, and in another by two Chinese workers.[9] It is interesting to note that in both schemes the group precipitates comprise practically the same cations.

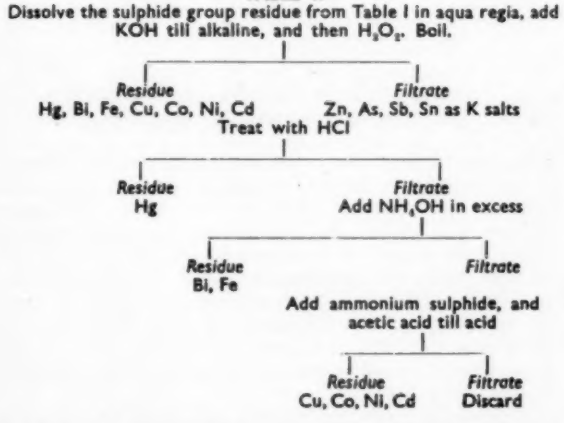
Cornog's scheme was devised for undergraduates, and uses few modern reagents. Group I is precipitated as usual, as shown in Table I. The alkaline earths

TABLE I


To a solution of the cations add HCl
Residue
Pb, Ag, Hg
Filtrate
Add H_2SO_4 and C_2H_5OH
Residue
Filtrate
Remove alcohol, add ammonium acetate, ammonium sulphide and acetic acid until acid. Boil
Residue
Hg, Bi, Fe, Cu, Co, Ni, Cd, Zn, As, Sb, Sn (Sulphide Group)
Filtrate
Add phosphoric acid and ammonia until alkaline. Boil
Residue
Mn, Mg, Al, Cr
Filtrate
NH_4, Na, K

and lead are then precipitated with sulphuric acid and ethanol. On removing the alcohol, the addition of ammonium acetate, ammonium sulphide and acetic acid precipitates the sulphides of mercury, bismuth, iron, copper, cobalt, nickel, cadmium, zinc, arsenic, antimony and tin. Manganese, magnesium, aluminium

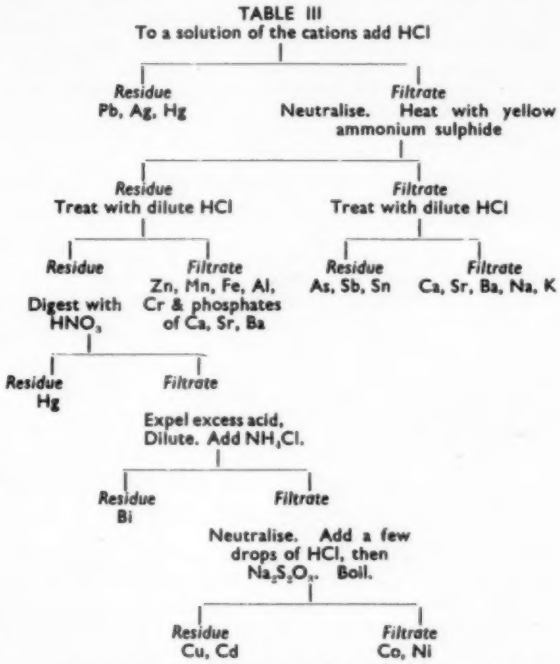
TABLE II



and chromium are then removed as phosphates, leaving the alkali metal in solution. It is claimed that zinc and manganese are more easily detected by this procedure than in the classical scheme, but it is also noted that mercury is liable to be missed. Detailed separation of the sulphide group, which contains eleven cations, is shown in Table II.

At least five schemes have been proposed which depend on the action of ammonium or alkali sulphides on the neutralised filtrate from Group I. Rawitch[10] devised a scheme of this nature, shown in Table III, in 1898. Group I is removed as usual, and the filtrate is

TABLE III



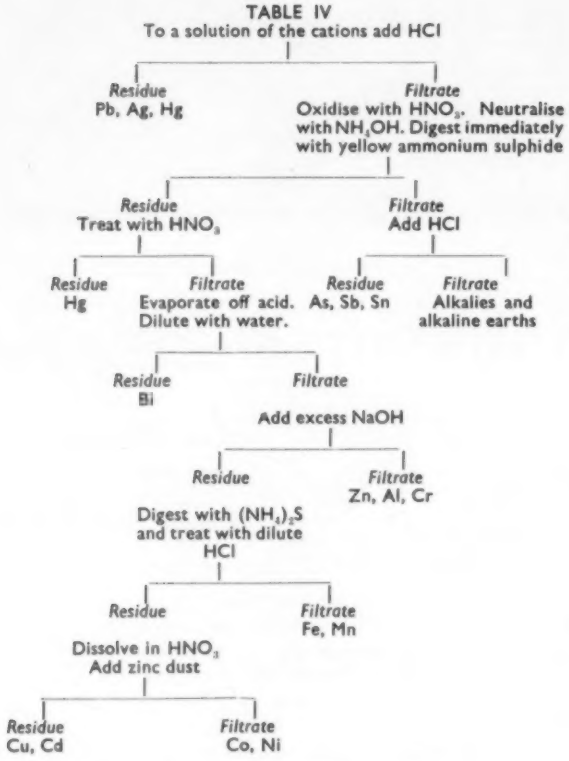
neutralised and treated with yellow ammonium sulphide. This leaves calcium, strontium, barium, sodium, potassium, arsenic, antimony and tin in solution. On treating the residue with hydrochloric acid, zinc, manganese, iron, aluminium and chromium go into solution. The residue is treated with nitric acid. Bismuth is removed as the oxychloride, and copper and cadmium as sulphides (with thiosulphate). Nickel and cobalt remain in solution. A slight rearrangement of the procedure is necessary when phosphate is present.

The scheme evolved by Trapp,[11] and shown in Table IV, resembles this closely in principle. Here the residue from the ammonium sulphide precipitation is treated with nitric acid, dissolving all but mercuric sulphide. Bismuth is then separated as the oxynitrate. Zinc, aluminium and chromium are taken out as the soluble sodium salts. The residue from this treatment is digested with ammonium sulphide and treated with hydrochloric acid, which brings iron and manganese into solution. The remaining residue is dissolved in nitric acid, and on the addition of zinc dust, copper and cadmium are precipitated, while cobalt and nickel remain in solution.

Tangonicang[12] has proposed a scheme which is almost identical with that of Rawitch. It is somewhat

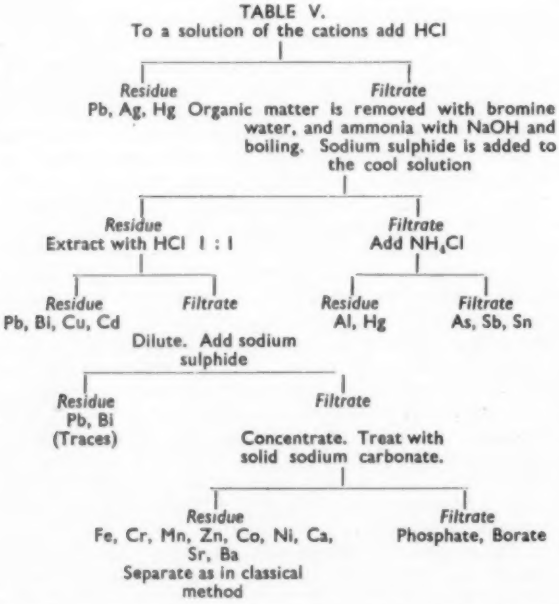
8 Cornog, *J. Chem. Educ.*, 1938, **15**, 420.
9 Chao and Hwang, *J. Chin. Chem. Soc.*, 1941, **8**, 21; *Chem. Abs.*, 1943, **37**, 53.
10 Rawitch, *J. Russ. Phys-chem. Ges.*, **30**, 761; *B.C.A.*, 1899, **78**, ii, 578.
11 Trapp, *Z. anal. Chem.*, 1912, **51**, 475.
12 Tangonicang, *Univ. Philippines Nat. and Appl. Sci. Bull.*, 1940, **7**, 423; *Chem. Abs.*, 1941, **35**, 708.

TABLE IV



simplified owing to the use of organic reagents for confirmatory tests, entailing less subdivision of the groups. Velgusevich,[13] who precipitates Group I in the classical way with hydrochloric acid, and the alkaline

TABLE V.



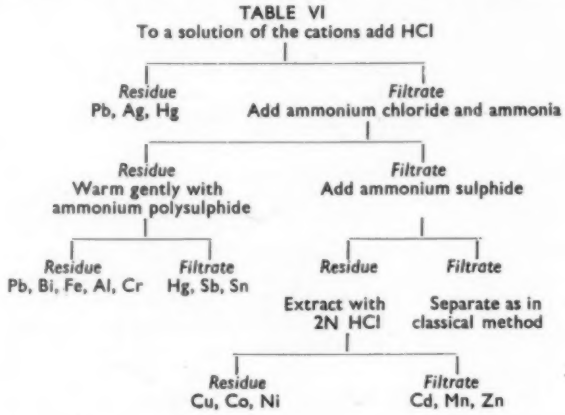
13 Valgusevich, *J. appl. Chem.* (*U.S.S.R.*), **13**, 1747 ; *Chem. Abs.*, 1941, **35**, 5406.

earths as sulphates, achieves a separation of the remaining cations with ammonium sulphide and ammonium polysulphide used in small amounts so as to avoid excess of the reagent.

Soldi,[14] as shown in Table V, uses sodium sulphide instead of ammonium sulphide, leaving aluminium, mercury, arsenic, antimony and tin in solution. The precipitate is extracted with hydrochloric acid, leaving copper, cadmium and most of the lead and bismuth as residue. The acid extract, after treatment with sodium carbonate to remove phosphoric and boric acids as the sodium salts, is analysed in the classical manner.

Herndon,[15] whose scheme is shown in Table VI, adds ammonia and ammonium chloride to the Group I

TABLE VI



filtrate, precipitating lead, bismuth, iron, aluminium, chromium, mercury, antimony and tin. The last three are then separated out by the action of ammonium polysulphide. The filtrate, on treatment with ammonium sulphide, precipitates cadmium, manganese, zinc, copper, cobalt and nickel. This group is also subdivided, hydrochloric acid being the reagent.

To be concluded.

14 Soldi, *L'ind. Chim.*, 1933, **8**, 159 ; *B.C.A.*, 1933, 365.
15 Herndon, *J. Chem. Educ.*, 1945, **22**, 183.

New Swedish Gauge Instrument Facilitates Steel Production

A NEW automatic Swedish micrometer, the Deltameter, is now being used for speeding up the production of the famous cold-rolled Sandvik strip steel by eliminating the necessity for manual control measurement. Invented recently by one of the company's engineers, C. G. Hard of Segerstad, the Deltameter outwardly resembles the dial indicators used by workshops to check surface smoothness, etc. Its compressed-air system permits measuring of tube dimensions, machine components etc., without requiring direct contact with the object to be measured.

When used in the rolling mill, the Deltameter gives a continuous record of the thickness of the strip steel, and it is also used for continuous remote control of the position of the rollers, adjusting immediately any divergence from the correct thickness with a very small tolerance.

Miscellaneous Microchemical Devices—XVII

Expedients in the Design of Complex Assemblies

By J. T. Stock and M. A. Fill

(*L.C.C. Norwood Technical College, London, S.E.27*).

IN the design of complex glass systems, it is usually desirable to make a preliminary set-up to ascertain the feasibility of the proposed arrangement. Rubber pressure tubing, used as described below in connection with glass tubing, rod, etc., has been found very useful in this connection.

A tee-piece that can be used not only under vacuum but also under reasonable pressure (e.g., that of town water supply) is shown in section in Fig. 1. The rubber pressure tubing is of 4 mm. bore and of similar wall thickness. With a sharp cork borer well lubricated with glycerine, a 4 mm. hole is cut squarely in the wall without penetrating the opposite side. One end of a suitable length of 7 mm. outside diameter heavy-walled glass tubing is then softened in the blowpipe flame and slightly expanded to form a strong, well-rounded collar about 9 mm. in diameter. When cold, the collar is wetted and forced into the hole in the wall of the pressure tubing. After the water film has evaporated, the rubber usually tends to stick to the glass, so that the resistance to blowing-out of the joint is increased. Owing, however, to the great leverage obtainable, there is never any difficulty in breaking the joint when required.

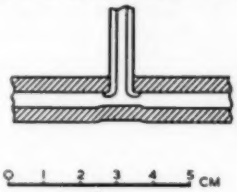


Fig. 1

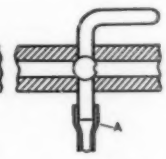


Fig. 4

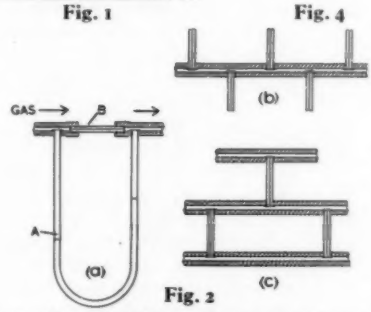


Fig. 2

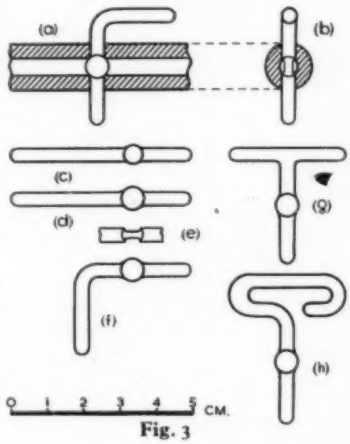


Fig. 3

Fig. 1.—Tee-piece for pressure or vacuum. Fig. 2.—Rapidly-assembled tube systems. Fig. 3.—Construction of stopcock with rubber body. Fig. 4.—Three-way stopcock.

The principle can, of course, be extended. At (*a*) in Fig. 2 is shown a simple flowmeter for low rates of gas flow. Appropriate sizes of U-tube A and orifice tube B may be rapidly assembled to meet the experimental conditions. The manifold shown at (*b*) and the cross-linking (*c*) are self-explanatory.

Where full-bore flow is unnecessary, an almost unbreakable stopcock may be constructed as shown at (*a*) and (*b*) in Fig. 3. A clean 4 mm. hole is first bored symmetrically and squarely *right* through a piece of 4 mm. inside diameter pressure tubing. The latter is then impregnated in the region of the hole with molten vaseline by the Pregl technique (repeated evacuation and readmission of air). To construct the plug, a sphere about 7·5 mm. in diameter is formed symmetrically on a length of 5 mm. diameter glass rod as shown at (*c*). Whilst still hot, the sphere is flattened as shown at (*d*) by pressing on a charcoal block with a flat-ended carbon rod. The thickness should then be a little less than the diameter of the rod, so that a flattened, round-edged disc about 10 mm. in diameter is produced, as shown in side view (*e*). Cutting to length, bending the handle and rounding the ends produce the finished plug (*f*).

To assemble, the lightly vaselined plug is merely forced into position as shown at (*a*). When the disc is "edge on," flow can occur between the walls of the tubing and the parallel sides of the disc, as shown at (*b*), and collapse does not occur under vacuum. When the plug is rotated through 90°, the way through the tubing is completely closed. If desired, the bent handle may be replaced by one of T-form as shown at (*g*) and (*h*). Other sizes of stopcock may be constructed from the appropriate pressure tubing and glass rod.

The special plug required for the three-way cock shown in Fig. 4 is not quite so simple to construct. It is made from 5 mm. outside diameter heavy-walled glass tubing, on which a sphere about 10 mm. in diameter is blown symmetrically. A hole about 2 mm. in diameter is then blown in the bulb at right angles to the axis of the tube and the projecting lip is then ground off by working with fine emery powder and oil on a piece of sheet glass. The plug is then cut to length and the handle is bent and the end closed as shown. The plug is then forced into place and the inlet connection made so that the flexible rubber tubing A is not twisted when the plug is intermediate between its two operating positions.

THE recent announcement that the name of P. R. Jackson & Co., Ltd., Hampson Street, Salford, has been changed to David Brown—Jackson, Ltd. is the outward sign of substantial developments of this associate of David Brown & Sons (Huddersfield), Ltd. now nearing completion. Extensions to plant to meet a demand for a wider range of heavy gears, gear units and steel castings have brought about an even closer collaboration between "Jacksons" and the parent organisation, and the change of name has been effected as a means of publicly acknowledging this liaison.

Corrosion Phenomena in Connection with Steel Pressure Cylinders used for Storage and Transport of Coal Gas

THE corrosion problems encountered during the transport and storage of gases in pressure vessels have been comprehensively and systematically dealt with by Schlapfer and Bukowiecki,[1] the work being based upon a study of the available literature and also on investigations conducted during a course of research, intended to elucidate the cause of the corrosion phenomena and to provide a pointer for the most effective means of protection that can be employed to combat the corrosion. The work that has been performed to date commences with an introduction comprising a review of all the available information and practical results that have been obtained previously in this field of research. No collected information under this heading has previously existed in the technical literature; this information is amplified and rendered all the more valuable by the critical study given by the authors.

First, a detailed discussion is presented of the gases which are handled in steel storage cylinders and of the materials of which the steel gas bottles are constructed. It is demonstrated that well dried gases, with only very few exceptions, do not attack, to any appreciable extent, the metallic constructional materials used. It is therefore necessary to pay particular attention to the question of moisture, which may be precipitated during the compression stage, if the gases have not been perfectly dried, or may be formed during some previous processing of the gas. This water is able to give rise to incipient electro-chemical corrosion, as the electrolytes required to establish this condition are formed in this way, as for example, in the lower part of oxygen cylinders. Alternatively, aggressive, corrosive solutions may be formed from the gas constituents, for example hydrochloric acid. A special case is provided by coal gas, which is of particular interest in this study; in addition to a general surface attack, which is caused by the CO_2, H_2S, NH_3, HCN dissolved in the precipitated moisture, there also occurs a certain amount of trans-crystalline stress corrosion. In this way, microscopic cracks may be formed in the steel, as Buchholtz and Pusch[2] were the first to demonstrate. Following this line of investigation, the authors showed that aqueous hydrocyanic acid, in the concentration in which it might be expected in the pressure cylinders, could be capable of causing the formation of such cracks. Whether, in every case, the failure observed by this fissuring has been caused by the hydrocyanic acid or whether also, other constituents of the coal gas should be regarded as accessory agents in this matter, has not yet been entirely clarified. The general opinion is now held however, that the hydrocyanic acid should be regarded as almost entirely responsible, but it still remains to be elucidated by way of further research, whether the fissures are caused directly or by way of the reaction products of this compound. The present authors and to a certain extent also, Buchholtz and Pusch have found during the course of their work, that in the first place, it is the harder steels which are the first to be attacked. The viewpoint has been generally held that, by the use of carbon steels with a carbon content under 0·4%, the danger of failure from stress-corrosion cracking may be more or less obviated, but this can hardly be regarded as a universal, satisfactory solution to the problem, because in this way it means sacrificing the technical advantages offered by a stronger and correspondingly lighter bottle.

The conclusions arrived at by the authors on this score, that a general means of obviating the cause of corrosion in these compressed gas cylinders, is to employ very thorough drying of the gas, has been fully confirmed in practice. However under practical conditions, this cannot always be carried out with the necessary safety and convenience. Thus for example, it has been demonstrated that the drying processes used up to now in the gas processing industries, have not always had the desired result. In Germany, co-ordinated research on this problem, conducted jointly by the technical societies, the gas manufacturers and the manufacturers of the compressed gas cylinders, has led to the opinion that the object may be achieved in a simpler and more certain manner by scrubbing out the hydrocyanic acid with water, as has been discussed by Eymann[3] in several papers, both from the theoretical and practical aspects. (HCN may be scrubbed out with the exception of just a small residual amount, and this can be achieved with even quite small concentrations of the compound in aqueous solution. On the basis of the previous research that has been carried out, it may be accepted that working in this way, all question of danger may be obviated. In addition, as has also been pointed out by Eymann in the work mentioned, this cleaning and purification of the gas also removes many of the difficulties formerly encountered during the high compression stages).

The final conclusions drawn from this review and work, for practical operations, show that this procedure is perfectly practical to use. It is emphasied however, that special attention must be devoted to the choice of the constructional materials used for the compressed gas cylinders. The question of possible protection against corrosion also, by means of protective coatings, is also considered, as well as the causes and prevention of severe corrosive attack. A most useful review of the technical literature on the subject is also given and this is all the more valuable because of the scattered nature of the references in the technical press.

1 *Monatsbull. Sch. Ver. Gas u. Wasserfachm.*, **28**, (1948) pp. 105–113.
2 *Stahl und Eisen*, **62**, (1942), pp. 21/30.
3 *Gas u. Wasserfach*, **88**, (1947), pp. 86/89; *Gas u. Wasserfach*, **89** (1948), pp 183/187.

Joining Heavy Aluminium Sections by Gas-Shielded Arc Welding

QUALITY welding of heavy-section aluminium and aluminium alloys has long been a problem of industry, but continued advances in inert gas-shielded arc welding techniques have gradually overcome the difficulties inherent in fabrication of this type. Outstanding among the advances made is the "Aircomatic" process, recently developed by the Air Reduction Sales Co. In this, heavy sections of aluminium and aluminium alloys are arc-welded by a continuously-fed consumable wire at wire feed speeds ranging from 100–300 in. per min. The consumable wire, fed through the barrel of the manual welding gun, replaces the non-consumable tungsten electrode conventionally used. Power is supplied from a standard D.C. welding generator and the arc is maintained between the the end of the wire and the work.

With the Aircomatic unit, welding of aluminium can be performed in all positions. Standard joint designs can be satisfactorily welded with the facility that is customary with metal arc welding of steel. In addition, however, the new process has the advantage of high deposition rate. This results in continuous filler metal feed and the absence of slag. No flux is required and little or no edge preparation or preheat is needed. The arc is always visible, thus eliminating the uncertainties incurred in blind welding. The application of this process to metals other than aluminium and aluminium alloys is now under development, but a combination of factors including current density, gas shielding, and filler wire feed speeds must still be determined before universal application of this process is possible.

For aluminium welding, as currently provided in this process, only three sizes of filler metal are needed: $\frac{3}{64}$ in., $\frac{1}{16}$ in., and $\frac{3}{32}$ in. With these sizes, the overall current range is from 70–450 amp. This permits welding of metal thicknesses from $\frac{1}{8}$ in. up to 2 in. and more. At the present time, only three types of wire are used.

The component parts of the new unit are: The welding "gun"; gas (argon) hose, concentric with which is the metallic tube for conveying the welding wire; a three-conductor control cable; feed motor box; control box; and wire reel.

The welding "gun" closely resembling an automatic pistol in size and feel, is equipped with a trigger which readies the unit for welding and a button for feeding wire when not welding. To start welding, the trigger is depressed. It can be locked in the "on" position. Depressing the trigger starts the flow of the shielding gas. The electrode, protruding about $\frac{3}{4}$ in. from the gas nozzle, is scratched on the work to produce the arc. Controls to energise the feed motor and delivery filler metal operate when the arc voltage is established.

In welding, the gun is held so that it points ahead in the direction of welding. To terminate a weld when no welding current contactor is used, the arc is broken with a quick snap. If a contactor is used in the circuit, the operator need only release the locked trigger.

From *Materials and Methods*, **29**, 2, 65.

Experiments on the Effect of Rolling Procedure and Annealing Temperatures on the Stress-Corrosion Resistance of Aluminium-Zinc-Magnesium Alloys

THE specimens used in the experiments contained, on the average, about 4·5% Zn, 3·6% Mg, 0·25% Cu, 0·25% Mn, and in some cases small additions (0·04–0·17%) of vanadium.

Cast billets weighing 3 kg. were extruded, hot- and cold-rolled down to a thickness of 1 mm., the sheet was solution heat-treated, aged at room temperature and tested for resistance to stress-corrosion by the loop test with alternate immersion in 3% NaCl solution.

In the first series of experiments the specimens differed in the number of cold reductions and in the magnitude of the final reduction in cold-rolling from the 9 mm. of the hot-rolled sheet down to the final thickness of 1 mm. The intermediate annealing temperature was 450° C., and the cold-rolled sheet was solution heat-treated at 450° C.

In the absence of vanadium there was no definite effect of cold-rolling procedure on stress-corrosion resistance, though, if anything, sheet rolled down with a number of small reductions and with the smaller final reduction was the better. This was definitely the case when the alloys contained additions of vanadium.

In a second series of experiments, the rolling of the extruded strips was commenced at 400°, 450°, and 500° C., respectively, the same temperatures being used, respectively, for the intermediate anneals in the course of the subsequent cold-rolling and for the solution heat-treatment of the specimens. The results of the stress-corrosion tests showed that, in general, the higher the temperature to which it was heated in rolling, and particularly for solution heat-treatment, the more susceptible the alloy was to stress corrosion.

The effect of vanadium additions is to raise the temperature to which the alloy has to be heated before developing a sensitivity to stress corrosion.

From *Metalloberfläche*, **2**, 7, pp. 137–140, July, 1948. Digested in *Light Metals Research*, **9**, 24.

Ruthenium

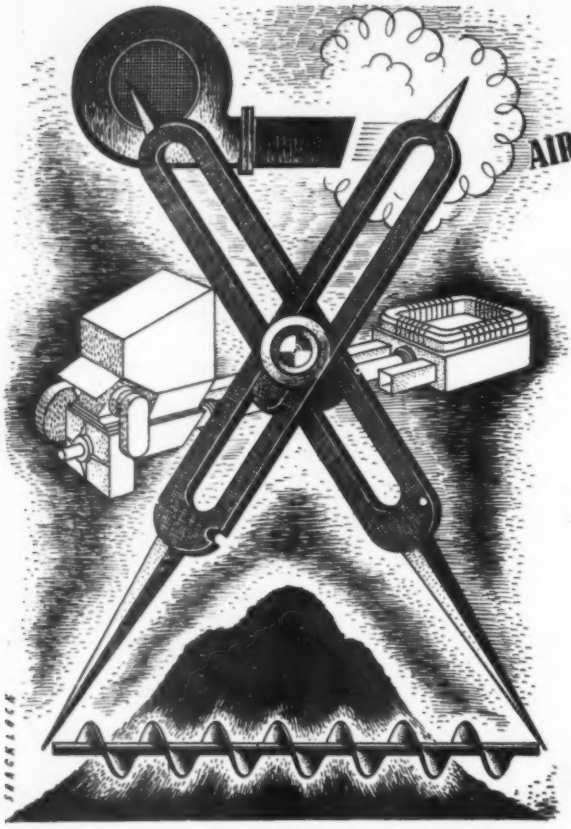
RUTHENIUM is one of the relatively rare platinum group metals. For every 1,000 oz. of platinum produced there are only 3 oz. of ruthenium. Accordingly, it is not surprising that one hundred years passed after the discovery and isolation of platinum before ruthenium was discovered. It was found in certain "platinum residues" by the Russian chemist, Karl Karlovich Klaus. The new element was named Ruthenium in honour of Russia.

Ruthenium has six valences: 2, 3, 4, 6, 7 and 8. There are ruthenates and perruthenates, such as K_2RuO_4 and $KRuO_4$. Ruthenium metal is steel grey. Its specific gravity is 12·3, as against 21·5 for platinum. The melting point is 2,450° C., as against 1,774° for platinum.

Ruthenium is highly resistant to acids but practically no use has been made of this nor of its other characteristic properties. A splendid opportunity for metallurgical research. Caution: Ruthenium salts are poisonous.

Wm. R. Mott[1] in his studies of the volatility of refractory materials in the

From *Bull. Electrochem. Soc.*, July, 1947.
1 *Trans. Electrochem. Soc.*, **34**, 279, 1918.



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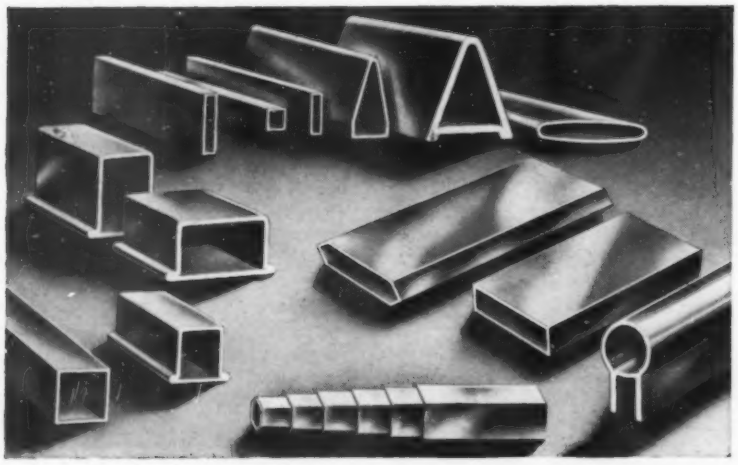

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ASTON CHAIN AND HOOK CO. LTD., BROMFORD LANE, BIRMINGHAM, 24.

carbon arc estimated the boiling point of ruthenium at 4,150° C., decidedly higher than the boiling points of platinum and aluminium oxide. In a later study[2] he reported that ruthenium gives a bright blue arc core and a yellow arc shell. A good bright metallic deposit was formed on the cathode tip.

Harold G. Bain[3] prepared metallized glass oxygen-electrodes of the platinum metals including ruthenium. The ruthenium solution used contained 1% ruthenium chloride in 4 normal hydrochloric acid. As in the cases of the other platinum metals no ruthenium electrode gave reproducible and constant values for the oxygen potential.

Ruthenium like osmium forms a hexacyanide, and M. R. Thompson suggests[4] electrodepositing ruthenium from a cyanide bath. Ruthenium dissolves in fused potassium hydrate. Tetravalent ruthenium forms a sulphide, a selenide and a telluride. The silicide is RuSi. Three chlorides and five oxides are known.

There are as yet few applications of metallic ruthenium, but prominent among these are the platinum-ruthenium alloys replacing the more valuable platinum-iridium alloys for pen points and electric contacts.

2 *Trans. Electrochem. Soc.*, **37**, 694, 1920.
3 *Trans. Electrochem. Soc.*, **78**, 173, 1940.
4 *Trans. Electrochem. Soc.*, **79**, 432, 1941.

Plain Bearings—To-day and To-morrow

By E. Crankshaw

PRESENT-DAY bearing materials have given a good account of themselves in their various proper applications. However, bearing failures are experienced and these are chiefly attributable to three factors: (1) Substantial increases in rated engine output without fundamental design changes; (2) improper installation; and (3) sustained demands of the engine beyond its designed intentions.

CHARACTERISTICS OF VARIOUS BEARING MATERIALS
(*Their relative importance considering their place in the bearing structure*).

·020 NOMINAL THICKNESS
BEARING SURFACE LAYER

Bearing Quality	Fatigue Resistance	Corrosion Resistance
Lead Base	Silver ..	Silver ..
Tin Base	..	..
	..	Tin Base..
Lead Tin Plate	Leaded Bronze	Lead Base
Cadmium		Lead Tin Plate
	Cadmium	
	Lead Base	
Silver	Tin Base..	Leaded Bronze
Leaded Bronze	Lead Tin Plate	

Recognising these existing conditions, the industry is in need of a bearing which will have the surface characteristics and corrosion and seizure resistance of the babbitt bearing, and load-carrying ability and fatigue resistance of the steel-backed copper-lead bearing. The present-day trimetal bearings, steel-backed construction, copper-lead intermediate layer and babbitt bearing surface, are fulfilling to-day's requirements. Research and development is in progress to improve this bearing and develop a new bearing which will meet to-morrow's demands.

With the present-day engines, which are operating under higher loads and speeds than ever before, it has become increasingly important that the bearings are installed under proper conditions. To do this a vast educational programme will have to be instituted throughout the entire industry, initiating with the manufacturer and being carried down through the service departments and corner garages. Proper instruction manuals and verbal instructions on running clearances, bearing-bore eccentricity, taper, hourglass, fillet ride, parallelism and twist finish, and shaft and case alignment must be distributed so that both new and rebuilt engines will show good bearing life.

To do this it will be necessary to be able to recognise and diagnose typical bearing failures such as fatigue wiping, dirt, and uneven wear and fatigue due to improper installation.

Much of this paper is based on information on engine design because of the availability of extensive data from engine operation as well as laboratory tests; nevertheless, many of the principles can be applied to the various bearing applications.

From paper before Am. Soc. Mech. Eng. Annual Meeting, 1948.

Digest from *Mech. Eng.*, Jan., 1949, 49–50.

Tools and Dies Bright Hardened and Brazed in New One-Step Process

By Samuel Damon and A. L. Pranses

IN the past furnace brazing has not been widely applied to tools and dies, primarily because the atmosphere requirements for tool steels have been largely unattainable in ordinary furnace equipment. Some furnace brazing of tool steels has been done where the content of easily oxidisable constituents, such as chromium, silicon, manganese, etc., was low enough to ensure oxide-free surfaces. The more highly alloyed steels can be brazed satisfactorily by the application of a flux to provide the oxide-free surfaces necessary for successful brazing, but it is often necessary to allow grinding stock on the assemblies to enable the removal of surfaces decarburised during the brazing cycle.

Development of the "Ammogas" furnace originally designed to bright heat-treat tool steels now makes possible the simultaneous brazing and bright hardening of these steels. The furnace is of the batch type, with both a heating chamber and a cooling chamber containing a protective atmosphere. Because of its unique design, the purity of the protective atmosphere can be preserved; an atmosphere of dissociated ammonia with a moisture content in the neighborhood of 0·01% can be maintained within the hot zone and cooling chamber. Satisfactory work may perhaps be possible without these refinements, but brazing fluxes are then required and the resulting work is not bright.

METHOD

With this process a tool steel assembly to be heat-treated is given the same heat-treating cycle in the furnace, just as if brazing were not being conducted. The brazing alloy is in wire or sheet form, and is simply placed in the immediate proximity of the joint to be brazed. If the joint has been properly prepared, as described later in this article, the molten brazing alloy will remain in the joint indefinitely due to the capillary forces. Thus the steel may be held at the

From *Materials and Methods*, **29**, 2, 58–61.

austenitising temperature for the proper soaking time. The steel, it of the air hardening type considered in this article, is quenched in the atmosphere protected cooling chamber, then tempered in the normal manner.

For successful brazing the tool steel assemblies must be properly prepared. Surfaces in and about the joint must be clean, free from foreign particles, oil and grease. A slightly rough surface is preferred within the joint to abet wetting and distribution of the brazing alloy throughout the joint. Of course, when close tolerance fits are required, as they would be in most tool applications, ground surfaces are required, but these can ordinarily be brazed successfully if all other precautions are observed. In instances where it is possible, a medium machined surface—intermediate between rough and finish machined—should be provided.

When putting assemblies through the furnace to be brazed, the relationship of the parts must be maintained from start to finish. Several typical ways this can be done are: (1) The simple hole and pin type of assembly should be a press fit allowing about 0·001 in. per in. interference on the diameter. (2) The force of gravity can be utilised. Since some movement may be expected during brazing, extra stock to be ground off after brazing must be allowed if this method is used. (3) Parts can be swaged or peened together. (4) Parts can be riveted or tack-welded together. (5) A common method, and one which will find the widest use when preparing tool assemblies, is that of holding parts together with screws or press-fit dowels.

BRAZING ALLOYS

Because previously copper had been used as the filler metal in furnace brazing of tools, this was the brazing material first employed in treatments carried out in the Ammogas furnace. Although copper gave excellent joints with even such tool steels as the high carbon-high chromium types, its melting temperature, 1981 F., is considerably higher than the optimum heat treating (austenitising) temperature for most tool steels. Hence, a double treatment was required. This involved heating to a point above the fusion temperature of copper to accomplish the braze, cooling, then re-heating and quenching per the normal heat treating cycle for the tool steel involved. A double treatment of this type minimises grain growth and austenite retention, and therefore is preferred to one wherein the metal is cooled only to the usual hardening temperature after brazing, then quenched. However, the double treatment is undesirable, both from the stand point of time consumption and the increased risk of distortion to the tool components.

Silver brazing alloys had long been considered unsatisfactory for use as the filler metal in tool steel assemblies, because of the lower strength displayed by such joints. The use of flux was previously considered compulsory, and clearances of 0·002 in. and greater were generally employed with such alloys due to the lower fluidity and penetrating power they displayed. It was felt that some improvement might result if these conditions were improved, i.e., the fits made interference or at least zero clearance and fluidity increased, since it is well known that maximum strength in brazed joints develops from minimum clearance if complete wetting is attained.

Since the furnace had been successfully applied to the simultaneous bright hardening and fluxless silver brazing of the 13% chromium, hardenable grades of stainless steel, even though press fits were employed, the value of an extremely pure atmosphere in increasing fluidity and penetrating power of silver brazing alloys was apparently established. The brazing material used in that development was a copper-silver-tin alloy with a melting range not far below the austenitising temperature of 1795°–1850° F. for this stainless steel. The excellent results achieved thus suggested the application of a similar technique to the joining of tool steels. In those cases where the heat-treating temperature demands a lower melting range, other silver brazing alloys such as 50% copper and 50% silver, which melt between 1435° and 1580° F., are available. Thus, for each of the widely used air hardening tool steels there is available a silver brazing alloy with a melting point or range lower than the austenitising temperature of the steel, but by not too great a margin.

The strength (almost always expressed as shear strength) of a brazed joint depends on many factors, such as surface cleanliness and condition of parent metal, tightness of the joints, time at heat, furnace temperature, subsequent heat treatment, etc. In general, a sound braze using copper in a press-fit joint with about 0·001 in. per in. interference can be expected to have a shear strength approaching 30,000 psi. if clean surfaces and optimum brazing conditions exist. Although this value is low compared to the shear strength of hardened tool steels, proper design can almost always minimise the need for strength in the brazed joint itself.

A test was conducted to compare the strength of a copper brazed assembly, which was subsequently heat treated, with a similar assembly simultaneously brazed and heat-treated using the 50% copper, 50% silver material. By recording the load required to push a pin that was brazed into the test samples it was possible to compute shear strength in lb. sq. in. Each sample was brazed and tested three times, thus giving 12 values for each brazing process. The data so obtained failed to show a size effect within the range of sizes tested.

The above data indicate that the simultaneous brazing and heat-treating operation produced joints of equal strength with those brazed with copper and subsequently heat-treated (double treatment).

APPLICATIONS

Experience has shown that the simultaneous brazing and heat-treating technique can be far more widely applied to the repair and modification of existing tools and dies than it has been in the past. Broken projections can be repaired by providing a replacement in the form of a brazed-in insert. Worn or indented areas can be repaired by brazing either tungsten carbide or tool steel wear plates into the die. Machining errors on costly tool parts involving the removal of too much stock can often be rectified by brazing in a block to replace the stock removed by mistake. Stress concentration points (shoulders, sharp corners etc.) which are essential to the design, and which often lead to subsequent fracture, can be reduced by making such components in two parts brazed together.

The broadest potentialities of this process lie in its application to those parts which by virtue of their complexity, involve much costly, complicated machining and hand finishing. By making such parts in several pieces to be subsequently brazed together, machining and hand-finishing can often be greatly facilitated.

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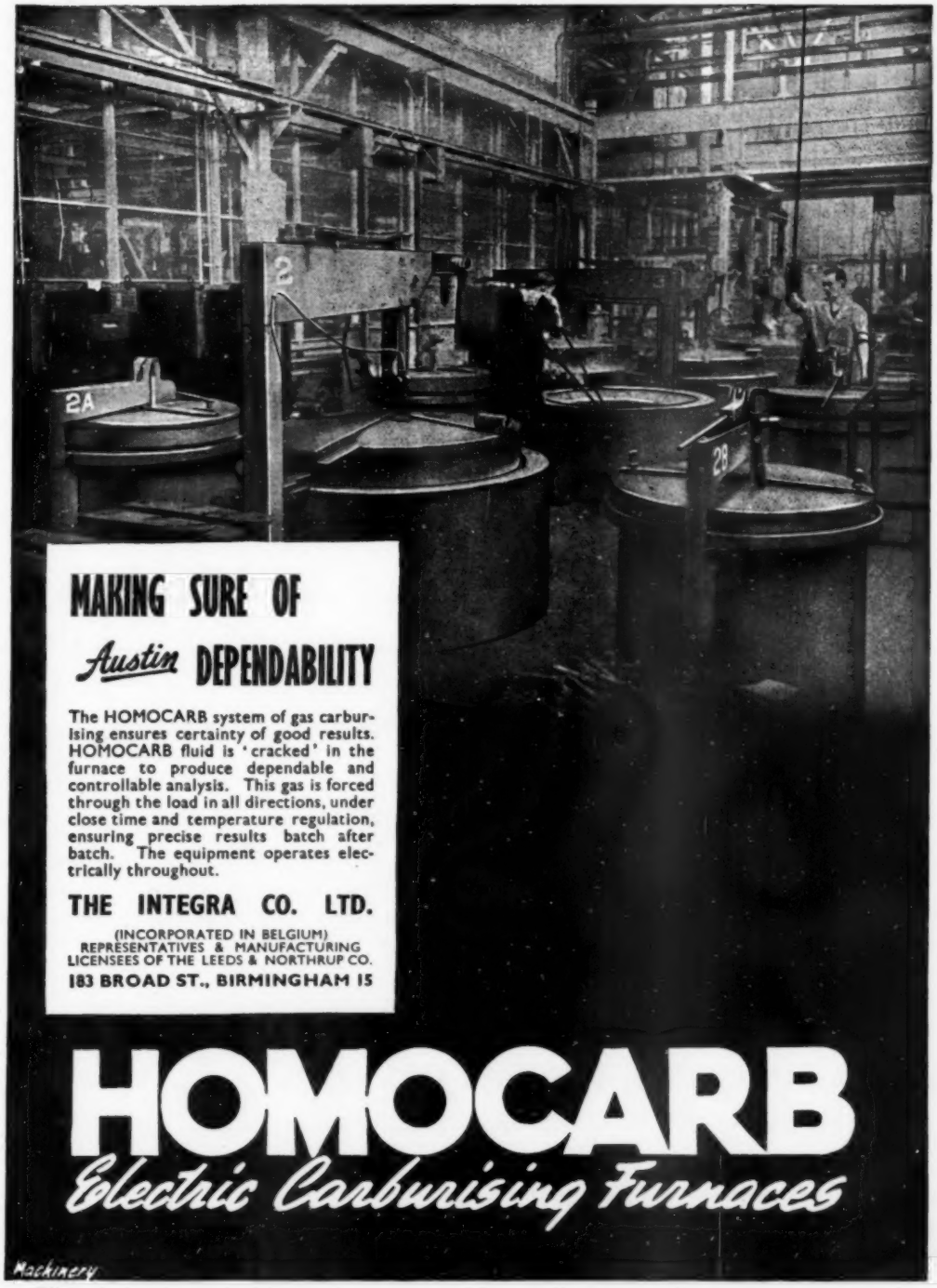
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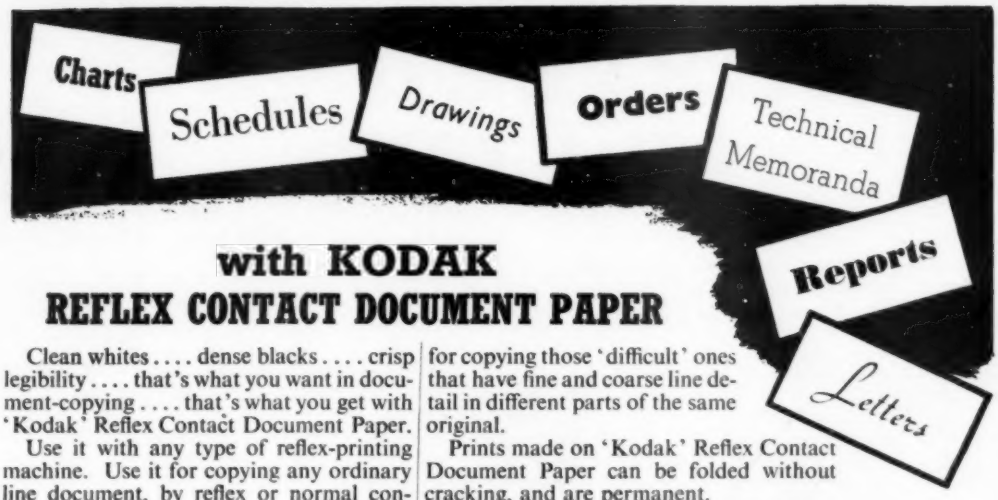

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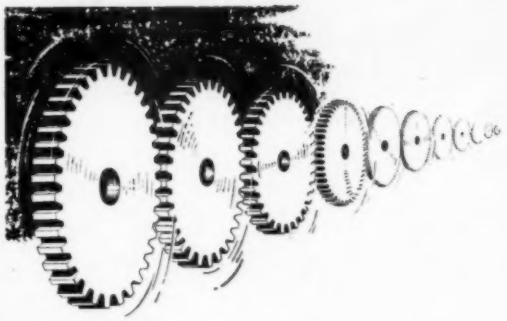

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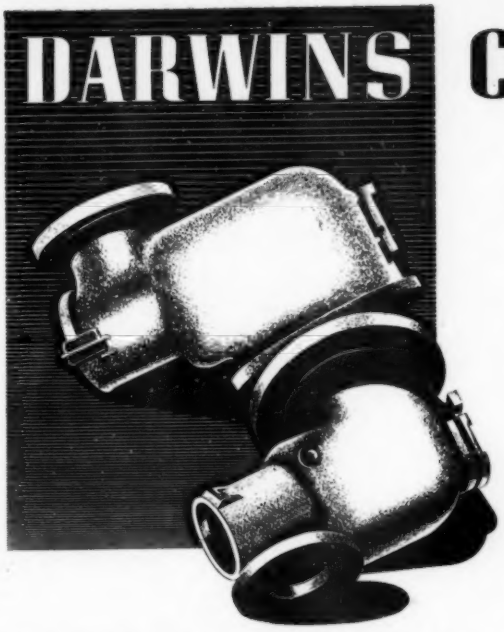

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MISCELLANEOUS ADVERTISEMENTS

SITUATIONS VACANT

Vacancies advertised are restricted to persons or employments excepted from the provisions of the Control of Engagement Order, 1947.

WORKS METALLURGIST required for General Engineering Works, Castlemaine, Victoria, Australia, employing 600 men. Young man, good education with experience modern methods of sand-mixing and testing, melting of ferrous and non-ferrous metals and high duty cast irons, also supervise heat treatment in forge and testing materials. Salary £800, house available at 30s. weekly. Applications with particulars to Box No. M.C.9, METALLURGIA, 31, King Street West, Manchester, 3.

NORTH ACTON engineering firm has a vacancy for a metallurgical chemist aged from 22–27 years, preferably holding a science degree, to act as assistant to the chief metallurgist. Sound theoretical training, mainly ferrous, practical outlook on works problems and good knowledge of modern plating technique necessary. Good prospects of advancement from the commencing salary rates. Factory is situated reasonably near the North Acton, Park Royal, Harlesden and Willesden stations and the No. 187 bus route passes the door. Please write stating age, experience and salary required to Box No. MB1, METALLURGIA, 31, King Street West, Manchester, 3.

SPECTRO CHEMIST FOR BIRMINGHAM LABORATORY. A well paid and responsible position is available for an experienced Light Alloy Spectroscopist, to take charge of this section in our Laboratories. Opportunity for research and development in Production Analysis as well as routine control. Male or female applicants. Write fully, giving age, experience, availability, etc., T. J. Priestman, Ltd., Cupro Foundry, Birmingham, 12.

A CHIEF RESEARCH METALLURGIST required for medium-sized Yorkshire Steel Manufacturing Company. In addition to a degree or qualification in chemistry and/or metallurgy, it is desirable for applicants to have five years' practical supervisory or executive experience in industrial works, preferably with some experience of steel manufacture, machine-shop practice, and application of steel to industry generally. Substantial salary to successful applicant, with possibility of house available. Please state age, experience, qualifications, and salary required. Box No. K.1, METALLURGIA, 31, King Street West, Manchester, 3.

METALLURGIST required as assistant to Plant Manager in department making powder metal products at works in Thames-side—Essex area. Some experience in powder metallurgy an advantage. Age between 25 and 30 years. Salary £450–£650 according to qualifications. Reply giving details of qualifications and experience, present salary, etc., to Box M.C.6, METALLURGIA, 31, King Street West, Manchester, 3

TWO qualified chemists required for the Laboratory of a light engineering firm in the South West, for Metallurgical and Miscellaneous analyses and investigations of a non-routine character, and to carry out a development programme on protective treatments of light alloys. Applicants must have a recognised qualification, and previous experience in a Works Laboratory would be advantageous. Both positions are permanent and offer scope for advancement. Apply stating age, experience and salary required to Box No. M.C.4, METALLURGIA, 31, King Street West, Manchester, 3.

JUNIOR Metallurgist, age 20–23 for laboratory and plant work. Sound Chemical knowledge and some practical heat-treatment experience essential. Write full particulars, Electric Resistance Furnace Co. Ltd., 161, Queens Road, Weybridge, Surrey.

HENRY WIGGIN & COMPANY LTD. (Nickel and Nickel Alloy Manufacturers) are expanding their Sales Organisation and require the services of a number of technically trained and experienced men for their Head Office in Birmingham and Area Offices. The positions to be filled include a Senior Executive having experience of export markets and a good knowledge of languages, a junior assistant for export duties, and three assistants in the Technical Service Department. Senior and Junior appointments will also be made for the area offices in London, Birmingham, Manchester and Glasgow.

Applicants, who should hold a university degree or similar qualifications, should write to the Managing Director, Wiggin Street, Birmingham, 16, giving full particulars of qualifications and experience.

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METALLURGIST. Degree standard, with experience of heat treatment and metal fabricating processes required to take charge and develop a section of the laboratory of a large engineering firm in Birmingham. Applicants should have several years practical experience of factory problems. Please state age, experience, qualifications and salary required. Box No. M.C.7, METALLURGIA, 31, King Street West, Manchester, 3.

METALLURGICAL ENGINEERS, with knowledge of German, are invited to apply for technical development post in Switzerland. Write Manager, Development and Research Department, Mond Nickel Company, Ltd., Grosvenor House, Park Lane, London, W.1. Mark envelope "S Confidential."

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Candidates should possess a degree or a Higher National Certificate or suitable C. & G.L.I. Certificates or an equivalent qualification in Engineering or Metallurgy.

Salary Burnham (Technical)—£300–£15–£525 with additions for approved industrial and teaching experience, degree and training. Further particulars may be obtained by sending stamped addressed envelope to Principal, to whom application forms should be returned within two weeks of appearance of this advertisement.

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Chief Education Officer.

PRODUCTION Metallurgist required for plant producing powder metallurgical products, situated in Thames-side—Essex area. Some experience in powder metallurgical practice essential. Good prospects for candidate with suitable metallurgical qualifications and experience. Age between 35 and 40 years. Commencing salary £800–£1,000 according to qualifications. Reply, giving details of qualifications and experience, present salary, etc., to Box M.C.5, METALLURGIA, 31, King Street West, Manchester, 3.

SITUATIONS WANTED

ELECTRICAL engineer, 14 years practical experience of physical metallurgy and application of metals to light engineering, with business experience, requires responsible executive or technical sales position, Box No.M.C.8, METALLURGIA, 31, King Street West, Manchester, 3.

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CONSULTING METALLURGIST, undertakes analyses, mechanical testing, referee reports, general routine work, technical advice and service in all branches, special investigations, private research, plant design and layout. BCM/PLANNING, London, W.C.1.

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